LARS Contract Report 083080

NASA-CR-167791

E83-10148

Quarterly Progress Report

(E83-10148) EVALUATION OF SLAR AND THEMATIC MAPPER MSS DATA FOR FOREST COVER MAPPING USING COMPUTER-AIDED ANALYSIS TECHNIQUES Quarterly Progress Report, 1 Jun. - 31 Aug. 1980 (Purdue Univ.) 57 p HC A04/MF A01 G3/43

N83-16823

Unclas 00148

Evaluation of SLAR and Thematic Mapper MSS Data for Forest Cover Mapping Using Computer-Aided Analysis Techniques

Contract No. NAS 9-15889

Reporting Period: June 1, 1980 - August 31, 1980

Submitted to: Exploratory Investigations Branch
NASA Lyndon B. Johnson Space Center

Prepared by: R. Hoffer, R. Latty, E. Dean, and D. Knowlton
Laboratory for Applications of Remote Sensing
Purdue University
West Lafayette, Indiana 47906

Technical Monitor: Mr. Norman Hatcher
NASA Mail Code SF5
Exploratory Investigations Branch
Houston, Texas 77058

Principal Investigator: Dr. Roger M. Hoffer
Ecosystems Program Leader
LARS/Purdue University
West Lafayette, Indiana 47906

TABLE OF CONTENTS

I. ACTIVITIES OF THE PAST QUARTER

A. Data Collection

1. Radar Data Collection and Evaluation

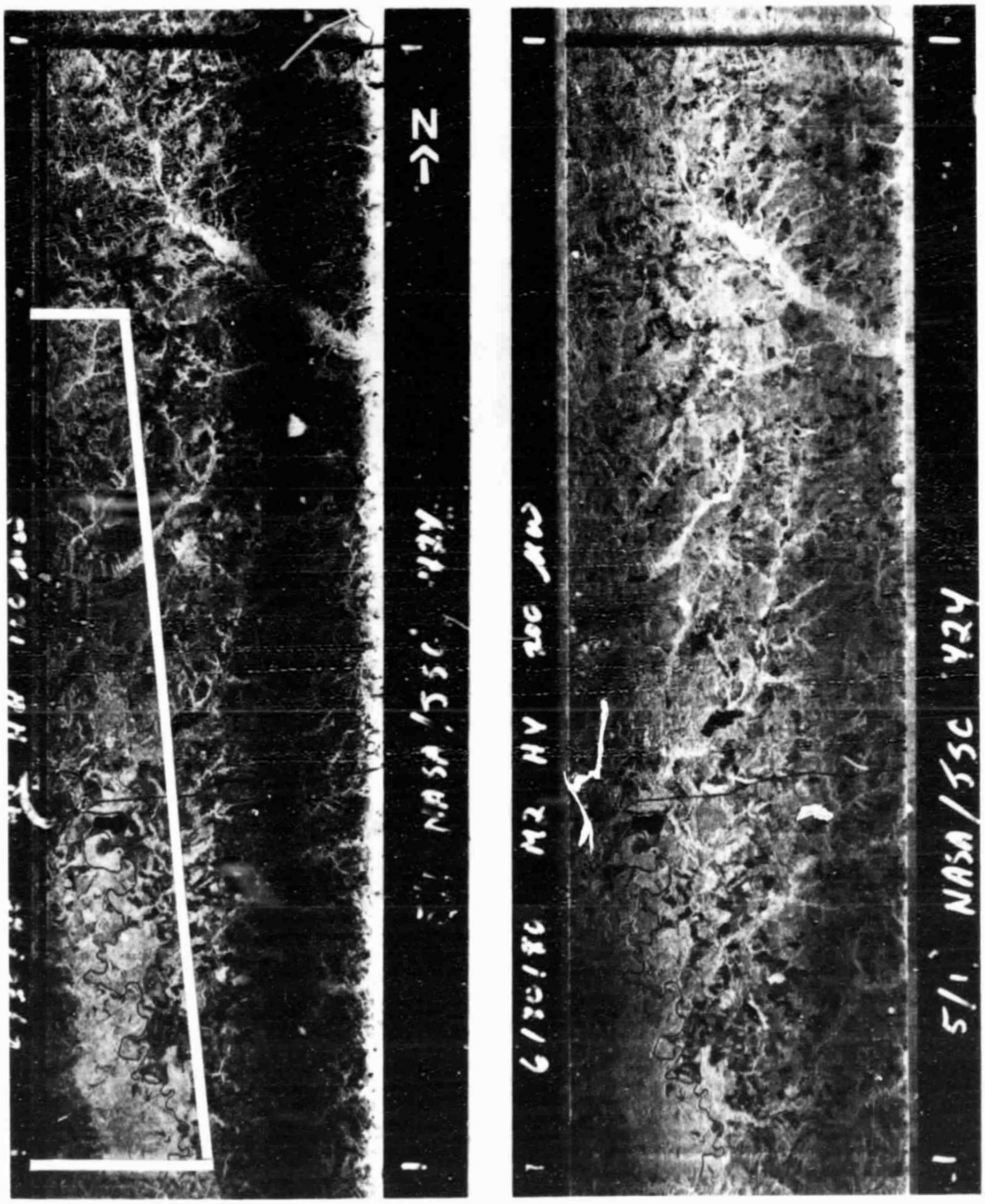
The radar mission, Mission Number 424, was successfully flown on June 30, 1980. This was the first radar data to be obtained in support of the current project. The sensor used was the APQ-102 side-looking radar, and the aircraft platform was the WB-57F flown at an average altitude of approximately 60,200 feet MSL. Small scale color IR photography was also obtained of the study site as part of this mission.

The APQ-102 side-looking radar is a fully focused synthetic aperature radar imaging system. A horizontally polarized pulse of energy of 9600 MHz ± 5 MHz (this wavelength band is commonly known as X-Band) was transmitted by the radar system, and the returning energy was recorded on separate holograms as horizontally (HH) and vertically (HV) polarized responses. These holograms were then processed through an optical correlator and the resulting images recorded on positive film, which was the format in which the data were provided by NASA to LARS.

The positive-map film was received at LARS on August 8, 1980. Black and white negatives and positive prints were then made of the radar film for handling and pre-analysis purposes.

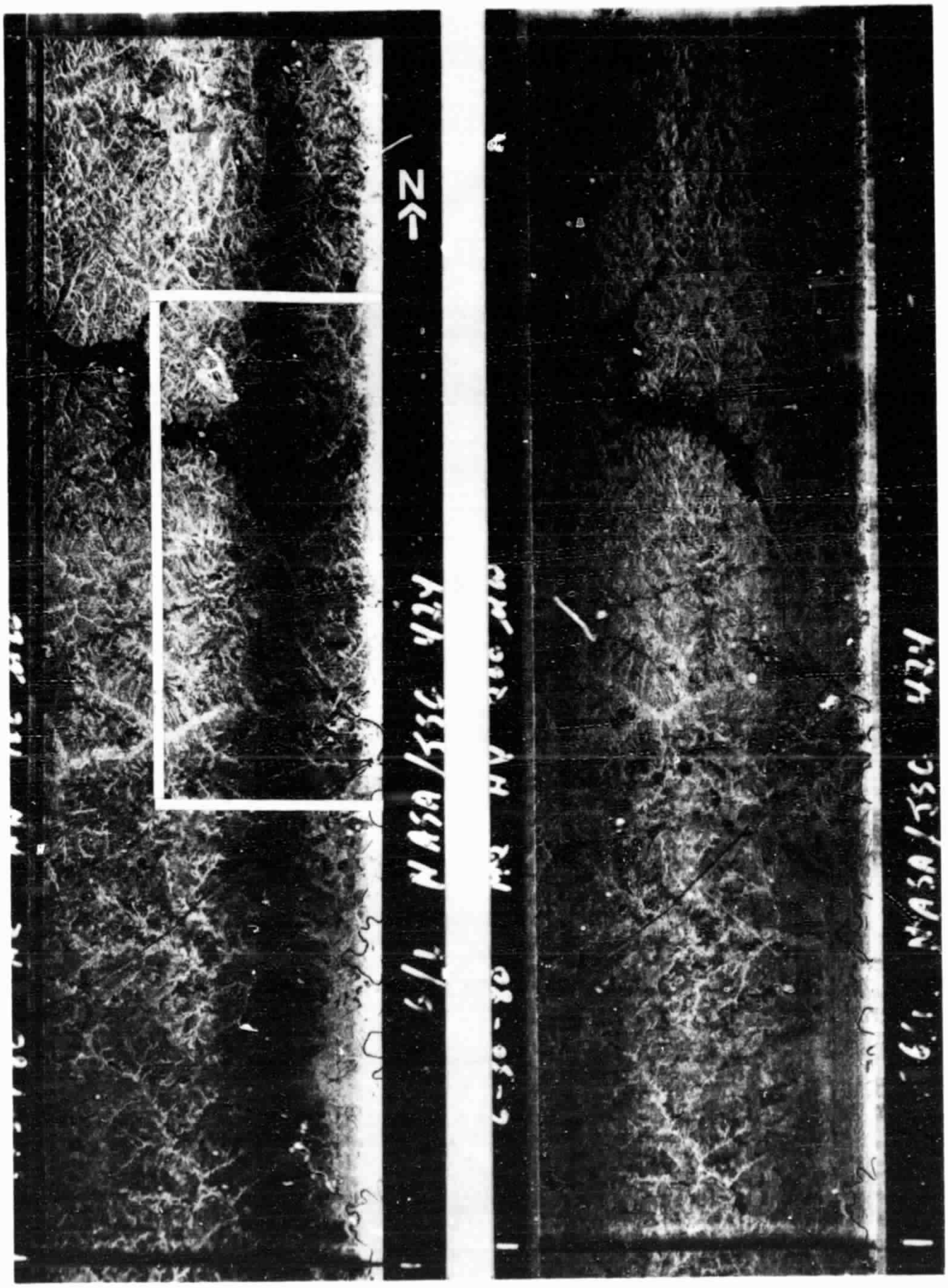
Visual comparison of the HH images and HV images indicates that there is a distinct dark band in the imagery which covers about 30 percent of the radar strip (see Figure 1). This band is very distinct on the HH images and is also quite noticeable on the HV images. Because the dark band falls on the test site for the Flight Line 2 data, the value of a detailed quantitative analysis of Flight Line 2 appears questionable (see Figure 2). However, the Flight Line 1 data looks reasonably good and the dark streak does not fall on the test site area, so this should provide a good data set for the quantitative analysis. Preliminary evaluation of the data indicates that various features on the HH and HV images seem to give different response levels, which provides promise for using this type of data to differentiate among various cover types and/or condition classes. This aspect of the data will be carefully studied.

The amount of sidelap due to the look-angle between Flight Lines 1 and 2 is negligible. This was surprising, since the flightline centers were defined to be only 5 n.mi. apart, but the swath width of the APQ-102 is 10 n.mi. Examination of the imagery indicated that the start (south end) of Flight Line 1 was exactly where it should have been, but apparently there was some drift as the aircraft flew up the flightline, resulting in a smaller portion of the test site being imaged at the northern end of the flightline (Figure 1). Flight Line 2 was flown 1-2 n.mi. to the east of the desired location, resulting in the lack of overlapping data. The slight amount of sidelap that does exist falls on the very edge of the data where the image quality is too poor to be of use. Since there is no useful sidelap in the data, analysis of forest cover as a function of look-angle (using the overlapping area of the two flight lines) cannot be pursued with this data set.



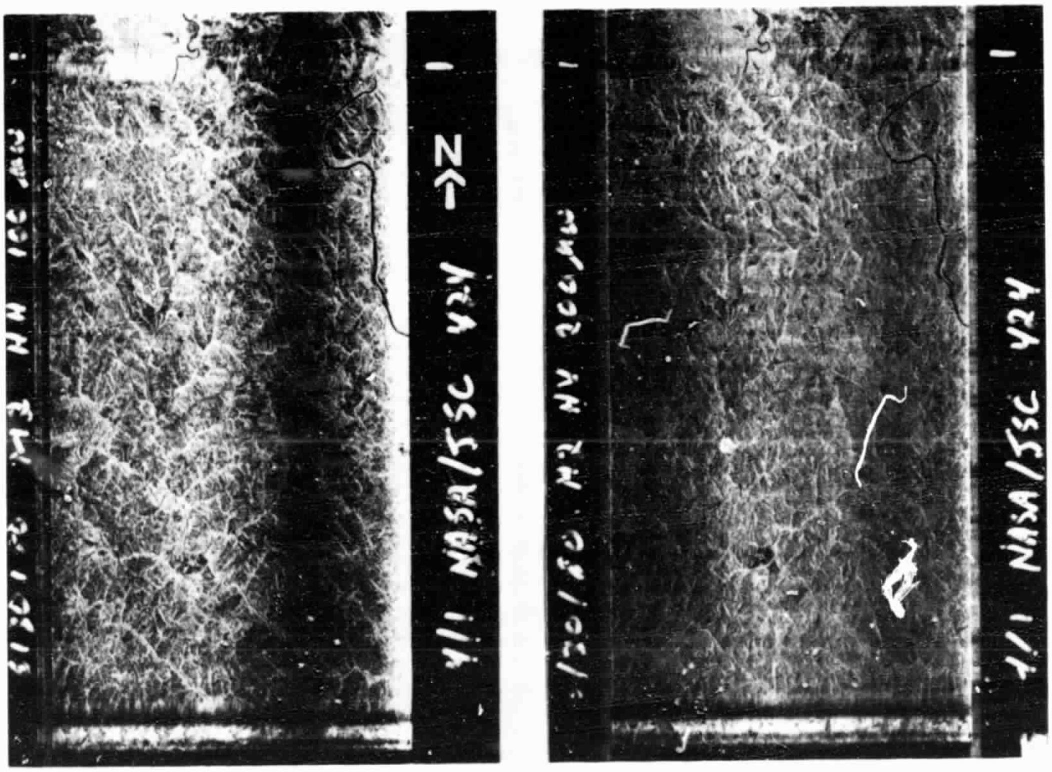
HH HV

Figure 1. Radar images of flight line 1 for the HH and HV polarizations. The corresponding area of the MSS data is outlined in white.



HH HV

Figure 2. Radar images of flight line 2 for the HH and HV polarizations. The corresponding area of the MSS data is outlined in white.



HH HV

Figure 3. Radar images of flight line 3 for the HH and HV polarizations.

An estimation of the scale in the "along-track" and "across-track" directions indicates that there could be a significant difference between them. The scales were determined by measuring the distance between two points on the radar images and the same two points on USGS maps; two different measurements were taken for each direction and the averages computed. The approximate scale for the along-track direction is 1:361,000 and the across-track direction is 1:413,000. Normally on fully focused SAR systems the along-track and across-track scales are the same (Tomiyasu, 1978). This is because the length of the flight line over which the signals are combined is equivalent to the along-track length of the illuminated area at far range for any given pulse (Greer, 1975) . Because of this relationship many variables can influence both the along-track and across-track scales, and thus create significant differences between the scales even though the system is a fully focused SAR system. The SAR system is a phase-coherent system and the differences or phase errors can be attributed to system imperfections such as radar-platform velocity deviations, targets in motion, electromagnetic path length fluctuations, and electronic equipment instabilities (Tomiyasu, 1978) . Since spatial characteristics, such as resolution and swath width, of the radar system are based on the same properties used to determine the scale, the system parameters must be evaluated to make an accurate determination of the spatial characteristics of this data set.

2. Multispectral Scanner Data Collection

NASA Flight Mission #425 to obtain three flightlines of NS-001 MSS data and supporting aerial photography was successfully flown on July 2, 1980. A summary of the support data is shown in Table 1 along with characteristics of the camera equipment used.

The Flight Line 3 data quality was very good and virtually cloud-free. Flight Lines 1 and 2 both contained some cloud cover especially in the northern sections and near the city of Camden, South Carolina and over the adjacent Wateree Reservoir. Flight Line 1 over Camden and north of the city contained between 30% and 40% cloud cover while south of Camden the cover was only between 0% and 10%. The quality of Flight Line 2 was generally better than on Flight Line 1 and contained only between 10% and 20% cloud cover north of and over Wateree Reservoir.

Mission #425 was continued on July 3 in an attempt to collect scanner data over Flight Lines 1 and 2 under more favorable weather conditions. The weather was generally very hazy, however, and in some areas over 50% of the imagery was covered by either haze or cloud cover. This situation occurred both north of Camden on Flight Line 1 and north of the Wateree Reservoir on Flight Line 2.

3. Field Trip to the Study Site

A field trip to the study area was conducted by Ellen Dean from July 1 to July 3 for the purposes of obtaining ground information concurrent with NASA Flight Missions #424 and #425, and to become better acquainted with the study site and the characteristics and variability of cover types.

Table 1. NS-001 Scanner and Aerial Photography Information: NASA Flight Mission #425

Flight #18
July 2, 1980
18:22:40 (time of flight)

Flightline	Run Time	Altitude (kft) MSL	Altitude (kft) MGD	Line Miles	Ground Speed (mph)	Blackbody Temp (°C)
1	6' 30"	21.4	20.9	35	299	14.8 (lo) 36.7 (hi)
2	6' 20"	21.7	21.2	35	300	14.6 (lo) 36.9 (hi)
3	3' 40"	21.4	20.9	22	297	14.9 (lo) 36.7 (hi)

Flight #19
July 3, 1980
14:52:35 (time of flight)

Flightline	Run Time	Altitude (kft) MSL	Altitude (kft) MGD	Line Miles	Ground Speed (mph)	Blackbody Temp (°C)
1	6' 30"	21.5	21.0	35	285	15.7 (lo) 32.7 (hi)
2	6' 30"	21.6	21.1	35	270	15.4 (lo) 32.7 (hi)

Film Type	Camera Type	Filter #1	Filter #2	Shutter Speed	Filter Factor	ASA	Focal Length	Forward Lap	Roll Number
S0397(C)	Zeiss	1A	36% T	1/250	2	160	6"	60%	22
S0193(CIR)	Zeiss	12	36% T	1/250	2	100	6"	60%	23

The first two days were spent in the field gathering reference information and color photographs of the various agricultural and forest cover types and conditions. These sites were located on aerial photographs from the previous NASA mission, Mission #399, noting the occurrence of any specific changes in the cover type. On July 3 a rental plane was flown over Flight Lines 1 and 2 at an altitude of approximately 900 feet above mean sea level and numerous aerial photographs were taken to be used in conjunction with other ancillary data to compare with data obtained from Missions #424 and #425. Subsequently these photographs were identified and labelled as to their corresponding positions on the CIR photos from Flight Mission #425.

To provide background information to use in the interpretation of the radar imagery, data on weather conditions was obtained for a period of one and two weeks prior to the flight missions (Table 2). This data was recorded at the Camden Weather Station, which is located in the center of Flight Line 1.

B. DATA ANALYSIS

1. Selection of Test Fields

A COMTAL Vision One/20 display device was used to aid in selection and photo interpretation of the test fields for the various spatial resolutions being investigated. Blocks of the geometrically and "radiometrically" adjusted imagery (see Quarterly Progress Report September 1, 1979 - November 30, 1979 for discussion) were used.

The first step involved designing a test sample grid such that the cover classes occurring at the various coordinates of the coarser resolutions could be identified using data of only one resolution displayed on the COMTAL. By designing the grid such that the set of pixels examined for the test pixel identification corresponded exactly with the set of pixels averaged in the resolution degradation program, the identifications made using the finest resolution data could be precisely mapped into the coarser resolutions. The spacing for the grid is thus determined by the smallest number for which all resolutions provide a common denominator. Since, for the across-track dimension, the resolutions are the average of 1, 2, 3, and 4 pixels then the spacing for the grid in the across-track dimension which will allow us to map exactly between resolutions is 12. Similarly for the along-track grid spacings; the pixels averaged together for each resolution are 1, 2, 3, and 5. Hence, the grid spacing must be a multiple of 30. The grid was generated by GRID·FTN (see Appendix B) for overlaying on the COMTAL image.

The COMTAL allows three different wavelength bands to be placed into separate image planes. These three planes can subsequently be assigned varying densities of red, green and blue colors, and overlaid to obtain a "truecolor" color composite image. This truecolor image was used, along with the ability of the COMTAL to magnify the image 1X, 2X or 4X, to accurately locate and identify the test fields. An example of this is shown in Figure 4 which displays one block of Flight Line 1 below Camden, South Carolina in magnification of 1X on which the Test Data Grid is overlaid. Figure 5 represents the central portion of the same scene at a 4X magnification.

Table 2. Weather Information from Camden, South Carolina

Date	Precipitation (inches)	Temperature (°F) (high)	(low)	Relative Humidity (Kershaw Co.)
6/16	0.15			
6/17	0.15			
6/18	0.55			
6/19	none			
6/20	none			
6/21	none			
6/22	none			
6/23	trace	92	57	50%
6/24	0.7	90	68	-
6/25	1.37	90	68	-
6/26	trace	78	66	87%
6/27	none	82	62	58%
6/28	none	97	66	-
6/29	none	99	70	-
6/30	none	96	72	40%
7/1	none	98	64	41%
7/2	none	92	71	

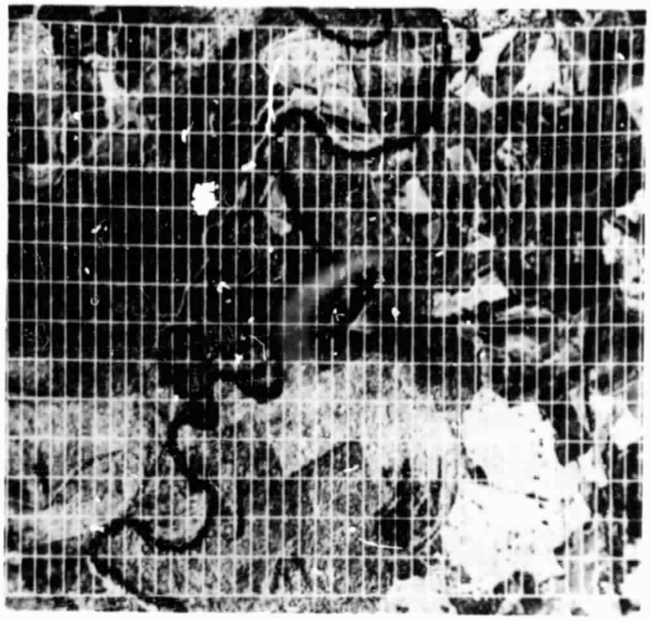


Figure 4: A COMTAL Vision/One image of Flight-line 1-S south of Camden, S.C. The image is overlaid with the grid used to locate and evaluate the test fields.

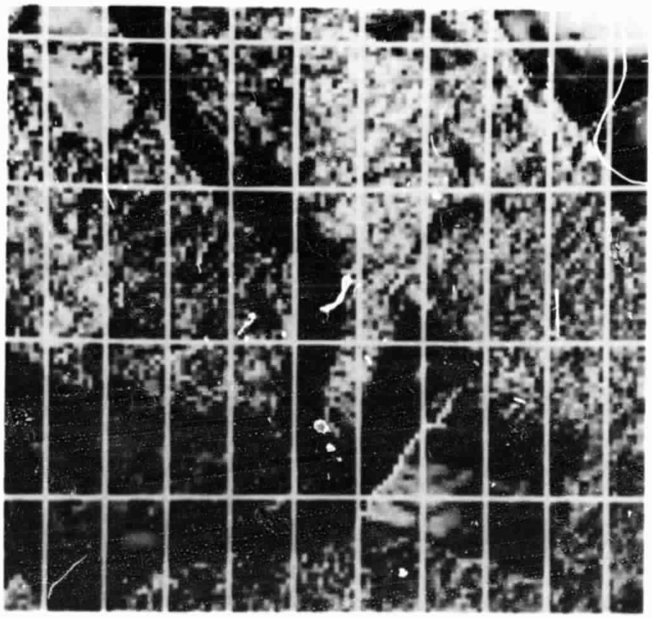


Figure 5: A magnification of a portion of the same image as shown in Figure 4. Magnification to this scale was used for most of the interpretation and identification of test fields.

Identification of the cover type in the test fields at all resolutions on the COMTAL was done in comparison with photo interpretation of the CIR photos. Identification into various cover types followed the format as outlined in the Quarterly Progress Report of June 1, 1979 - August 31, 1979, except for an additional class of tupelo which was found to be both visually and spectrally separable. All test fields at the various resolutions were evaluated separately and any border test fields, i.e., pixels containing more than one cover type at a particular resolution, were excluded from the final data set. The COMTAL coordinates and the test point identifications were recorded for subsequent translation into MIST coordinates for each resolution. This work has been completed for Flight Line 1-S. Blocks in Flight Lines 1-N and 2-N are currently being analyzed.

2. Waveband Combination Evaluation

Much of the work conducted in waveband combination evaluation for this project is discussed in a paper prepared for presentation at the Fall Technical Convention of the American Society of Photogrammetry. A copy of this paper is included as Appendix A. Review of that article prior to reading the following text is suggested, as duplication is avoided wherever possible. However, there were several considerations and activities of the work that were not reported in the appended paper. The following discussions will focus primarily on these details of the analysis.

The a priori estimation of the probability of correct classification employing a measure of statistical difference between spectral classes relies heavily on: 1) the degree to which the group of class densities represent the distributions of spectral response vectors associated with each cover class (Swain, 1978) and 2) the degree to which the set of class densities is exhaustive of the range provided by the response vectors from the area to be classified (Wiersma and Landgrebe, 1979). If the class densities satisfy the above conditions, then statistical separability of the class densities should provide a fairly reliable estimate of percent correct classification.

The actual computation of transformed divergence, as well as the vast majority of other "separability" measures, involves only two class densities for each individual computation or value. Transformed divergence is thus a measure deemed appropriate for a two class case of equal a priori probability. A problem arises when such a measure is to be employed to provide an estimate of overall percent correct classification involving a multiple of spectral classes of unequal a priori probabilities. This problem is further compounded by the fact that subsets of these classes represent different cover classes.[1/] The averaged transformed divergence is given by:

$$TD_{ave} = \frac{1}{n} \sum_{k=1}^{n} TD_k \qquad (1)$$

for n number of spectral class pairs.

[1/] The need to provide estimates for only relative percent correct classifications for purposes of ranking possible waveband combinations does not alleviate the problem.

However, the relative frequency of each spectral class pair is assumed constant in such an approach. This is rarely the case.

An unweighted, arithmetic average of all TD-values will result in the separability of two infrequently occurring classes having equal impact on the percent correct classification estimate, as the separability of two common classes. Consider the following:

Given a probability space S, $s_{ij} \in S$, $i = 1, \ldots, k-1$, $j = i+1, \ldots, k$ for each j, where k = the total number of spectral classes. If each s_{ij} is considered the simultaneous occurrence of each spectral class of the pair (s_i and s_j), the occurrence of each being independent of the other, then the probability of the occurrence of the "spectral class pair" can be determined by:

$$W(s_{ij}) = P(s_i)\, P(s_j); \quad (s_i \cap s_j) = \emptyset \qquad (2)$$

$W(S_{ij})$ is a weight, distinct from the probability associated with an occurrence. To ease the complexity of indexing, it is assumed here that each cover class is represented by only one spectral class. The computations are easily extended into the case where the number of spectral classes in each cover class is greater than one. Then an unbiased estimator of averaged transformed divergence, corresponding more closely to probability of correct classification is given by:

$$TD_{ave} = \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} W(s_{ij})\, TD_{ij} \qquad (3)$$

These probabilities should be treated with caution, as they are directed merely at extending the application of statistical distance as an estimator of probability of correct classification from the two class case to the multi-class case. The above presentation also assumes the availability of estimates of the $P(s_i)$ and $P(s_j)$. These are empirically derived using the relative frequency of each spectral class in each cover class and the relative frequency of each cover class. Computationally:

$$P(s_i) = P(s_i/C_\alpha)\, P(C_\alpha) \quad \alpha = 1, \ldots, m \qquad (4)$$

where: $P(C_\alpha)$ is given by the total number of pixels in the training data in cover class α divided by the total number of pixels from all cover classes in the training data.

$P(s_i/C_\alpha)$ is given by the total number of pixels in the training data spectral class s_i, which is a subset of C_α, divided by the total number of pixels in cover class C_α.[2/]

[2/] As may well be apparent, the algebraic identify of these probability estimates provides a computational shortcut to the probabilities of interest.

While these frequencies are easily obtained, their use in providing unbiased estimations of the above probabilities is dependent on each observation being randomly selected. That is, the selection of each additional pixel in developing the training data is completely at random. While this is rarely the case, the extent to which this assumption is violated will erode the "goodness" of each $P(s_{ij})$ and hence the resulting TD_{ave}. This has been used by some researchers as the rationale for not weighting each observed TD_{ij} and employing the unweighted arithmetic mean in the multiclass case. While this may well be warranted in many cases, it must be reconciled that weights are <u>always</u> employed. Where they are not computed and employed in the summation, they are merely assumed equal. Obviously,

$$\frac{1}{n}\sum_{k=1}^{n} TD_k = \sum_{k=1}^{n} \frac{1}{n} TD_k \tag{5}$$

The problem then becomes one of assuming some set of population parameters $(x_1, x_2, x_3, \ldots, x_k)$ where k is the number of spectral classes contained in the population and the x_i are the total number of pixels belonging to each i^{th} spectral class. The actual probabilities are then,

$$P(x_i) = x_i \left[\sum_{j=1}^{k} x_j\right]^{-1} \tag{6}$$

Then for the weighted as opposed to the unweighted case:

$$E_1 = \sum_{j=1}^{k} |\hat{P}(x_i) - P(x_i)| \tag{7}$$

and

$$E_2 = \sum_{j=1}^{k} |\frac{1}{k} - P(x_i)| \tag{8}$$

where E_1 is the error for the weighted case and E_2 is the error for the unweighted case,

is $E_1 \geq E_2$?

This is the consideration which, in spite of not being testable, must be resolved before proceeding with any multiclass case employing averaged statistical distances.

While an in-depth evaluation of this proble is beyond the scope of this study, the evaluation of waveband combinat_ons employing the weighted average was considered imperative for complete treatment of this part of the study. Table 3 provides a rank ordering of channel combinations for each waveband combination level for the weighted mean TD-values.

The work in waveband combination evaluation prompted the development of several programs which were written to be compatible with LARSYS. These are listed in Appendix B with brief descriptions.

Among these was a program which computed average transform divergence over all spectral class pairs for each cover class pair and over all spectral class pairs for each cover class. The tables of these results are shown in Appendix C, and provide insight as to the dependency of waveband combination rank on cover class composition of the area to be classified. Such output will also assist individual users of diverse interest to select those waveband combinations most suited to their particular application. By selecting that waveband combination of maximum TD_{ave} in cover classes with which they are concerned, the classifier can be "fine-tuned" according to the users needs. The disagreement between max(TD_{ave}) by cover class, cover class pair, and overall cover classes is very common.

Separability by cover class pairs will also provide information on which cover classes may require additional spectral classes in order to reduce their variance. It will also give an estimate of the results to be expected in the omission-commission error matrix.

3. Spatial Resolution Evaluation

The development of test statistics have been completed for the southern half of the easternmost flight line (Flight Line 1-S) for all resolutions (i.e., 15x15, 30x30, 45x45 and 60x75 meter data sets). Prior to generating all of the statdecks for each resolution, an evaluation of the spectral classes for the 30 meter data was conducted by classifying the training fields.

As indicated in the paper included as Appendix A, statistics for each class density were provided by a supervised cluster approach. The line-column coordinates of supervised samples of each cover class were identified from the COMTAL Vision One/20. These coordinates were translated into MIST coordinates and a LARS-12 card deck was generated by CAGEN2 FORTRAN (see Appendix B). These were then sorted by cover class and separate cluster analyses were run for each cover class. The individual statistics decks were merged, providing 32 spectral classes for 12 cover classes. Table 4 contains the resulting class parameters by spectral class, by cover class.

Separability indicated that these class densities were on the average, very separable and that acceptable classification accuracies could be expected. However, in order for class densities to provide high classification accuracies the classes must be:

1) representative of the distribution of observations of the same class,

2) separable or distinguishable among all other classes,

3) exhaustive of the sample space from which observations are drawn.

Table 3. Rank Ordering of Best Seven Channel Combinations for each Channel Combination level (ordering criterion is Average Transformed Divergence over all spectral class pairs).

1	2	3	4	5	6
6	3,4	3,4,5	1,3,4,5	1,2,3,5,6	1,2,3,4,5,6
3	3,5	3,4,6	3,4,5,6	1,2,3,4,6	1,2,3,5,6,7
4	2,4	3,5,6	1,3,4,6	1,2,3,4,5	1,2,3,4,6,7
5	4,6	2,4,5	2,3,4,6	1,3,4,5,6	1,2,3,4,5,7
1	3,6	1,3,4	2,3,4,5	2,3,4,5,6	1,2,4,5,6,7
2	2,5	2,4,6	2,3,5,6	1,2,4,5,7	2,3,4,5,6,7
7	5,6	2,5,6	2,4,5,6	1,2,4,5,6	1,3,4,5,6,7

Note: Channel 1 = 0.45 - 0.52 μm
Channel 2 = 0.52 - 0.60 μm
Channel 3 = 0.63 - 0.69 μm
Channel 4 = 0.76 - 0.90 μm
Channel 5 = 1.00 - 1.30 μm
Channel 6 = 1.55 - 1.75 μm
Channel 7 = 10.4 - 12.5 μm

ORIGINAL PAGE IS
OF POOR QUALITY

Table 4 . Summary of Statdeck Containing 32 Spectral Classes.*

	1	2	3	4	5	6	7
SOIL1	154.87	177.14	189.70	191.14	188.11	169.22	143.31
	243.34	635.95	755.00	320.86	308.40	513.50	757.91
SOIL2	129.42	125.67	128.85	135.62	144.49	144.83	139.44
	88.26	194.42	240.09	223.42	158.03	158.41	1162.87
SOIL3	111.10	95.63	92.80	99.29	109.41	106.21	135.06
	105.86	235.72	378.18	361.95	331.33	396.72	734.38
PAST1	93.84	74.46	62.05	118.41	122.58	91.51	137.99
	24.88	41.55	92.69	259.57	197.63	90.66	432.61
PAST2	87.89	65.24	44.09	155.37	135.89	68.69	86.19
	22.39	38.95	24.31	140.19	93.50	68.85	74.75
PAST3	85.36	61.38	42.37	119.42	106.93	57.08	80.27
	20.05	27.50	40.48	258.94	140.35	57.77	122.54
PAST4	96.11	72.86	57.77	38.39	31.09	22.08	45.94
	9.05	22.52	21.87	103.32	112.83	77.18	322.49
CROP1	117.65	111.12	100.67	172.25	161.50	119.58	103.02
	42.54	130.55	309.76	203.03	140.88	229.87	221.09
CROP2	100.77	76.21	52.34	210.17	160.62	68.76	82.34
	5.90	16.76	22.41	176.97	39.00	40.72	40.46
CROP3	99.82	82.30	71.21	118.67	117.97	91.60	137.56
	37.79	37.85	70.78	115.25	119.15	203.40	268.31
CROP4	96.03	76.84	59.45	150.22	127.02	64.76	97.05
	6.16	30.63	45.40	199.89	141.36	70.29	194.52
PINE1	92.26	69.76	54.05	113.46	115.17	71.85	116.23
	3.11	6.35	13.48	81.46	55.40	50.93	298.47
PINE2	94.75	67.90	48.67	118.79	112.27	59.60	83.64
	15.59	8.73	5.99	104.89	83.46	40.22	73.18
PIHD1	91.69	69.46	55.44	109.79	110.61	70.28	127.44
	14.58	8.39	11.96	64.06	46.92	28.63	379.38
PIHD2	94.31	65.79	46.95	112.63	105.95	53.95	84.25
	6.04	7.81	7.09	119.94	85.44	29.96	54.55
HDWD1	84.36	61.83	42.03	140.62	125.34	63.56	84.96
	9.19	19.05	14.24	228.86	171.32	67.09	98.88
HDWD2	91.78	70.90	59.56	99.01	101.23	76.16	125.33
	24.90	47.12	121.63	610.36	911.00	679.66	909.75
SGHD1	91.42	67.31	44.23	175.67	150.73	71.57	84.74
	7.13	9.40	5.47	55.54	38.43	29.82	55.83
SGHD2	86.10	51.11	40.46	155.12	133.78	63.66	81.08
	32.01	20.54	6.09	54.63	29.75	17.06	80.64
SGHD3	91.52	64.64	41.91	131.63	112.29	56.05	68.85
	13.22	9.93	6.45	126.96	92.78	16.65	34.31
TUPE1	84.63	61.26	41.99	134.63	119.80	60.42	80.56
	4.51	12.07	15.19	366.89	253.77	69.31	146.03
TUPE2	78.38	50.18	38.94	44.15	45.85	35.99	112.04
	3.70	15.81	23.85	168.05	386.93	304.10	809.13
SYCA1	87.53	66.20	50.40	123.40	124.13	82.87	116.73
	2.98	4.69	13.40	368.97	204.27	11.41	105.64
SYCA2	84.40	60.05	39.70	130.50	115.20	56.95	90.05
	2.15	4.58	7.80	294.47	167.96	28.58	35.84

Table 4 . Summary of Statdeck Containing 32 Spectral Classes (cont'd.).

	1	2	3	4	5	6	7
CCUT1	99.76 47.58	82.77 106.86	83.39 286.95	91.37 384.24	102.79 297.92	102.02 423.73	136.91 167.45
CCUT2	84.78 17.53	63.53 36.59	44.63 43.53	141.22 238.84	128.27 127.66	69.31 81.24	93.55 197.84
MVEG1	102.64 22.73	79.12 73.10	65.10 174.96	110.00 58.54	123.25 51.46	89.91 102.11	123.56 204.00
MVEG2	100.76 8.90	76.83 20.02	52.67 14.56	123.72 173.99	112.42 118.27	64.49 66.70	80.16 113.35
TUWA1	172.62 107.95	195.62 279.16	139.18 79.42	55.29 94.48	37.92 120.65	27.02 95.07	76.42 28.94
VEGE1	126.09 152.90	114.84 502.66	88.24 386.20	104.06 242.39	95.88 392.74	63.05 204.26	90.47 115.30
VEWA1	107.63 19.90	82.53 36.65	55.08 27.39	61.83 119.81	57.93 111.52	42.91 59.06	88.04 29.35
WATR1	107.05 43.52	78.41 123.32	52.51 31.17	39.08 13.04	33.06 17.75	24.97 14.22	71.62 143.33

*Within each spectral class, the upper element is the mean and the lower is the variance.

Channel Number	Band
1	0.45 - 0.52 μm
2	0.52 - 0.60 μm
3	0.63 - 0.69 μm
4	0.76 - 0.90 μm
5	1.00 - 1.30 μm
6	1.55 - 1.75 μm
7	10.4 - 12.50 μm

The degree to which Condition 2 is met is indicated by TD_{ave} or *SEPARABILITY. Condition 1 and 3 are truly only evaluated at the time of classification. However, Condition 1 can be partially evaluated by classifying the pixels contained in the training fields. While this "test" is only sensitive to the location of class densities in the q-variate hyperspace relative to the individual response levels, it is a very good means of testing whether these class densities correspond to "regions" of concentration as they exist in the data. This idea is confirmed by the change in spectral class variance for a cover class with respect to changes in the number of spectral classes.

The training fields were classified using a per-point Gaussian Maximum Likelihood (GML) classifier (a priori probabilities were assumed equal). The training classes were the 32 spectral classes presented in Table 4. The classification result using all seven channels (channel calibration code 7) is provided in Table 5. Overall classification was only 47.4%. Although these cover classes are fairly specific in nature, the reasons for the resulting accuracy level were investigated. Examining the error matrix indicates extremely low classification accuracies for pasture, hardwood, tupelo, sycamore, and clearcut. The number of spectral classes representing each of these categories are 3,2,2,2, and 2 respectively. By increasing the number of spectral classes (re-clustering with a greater number of cluster classes specified) to a total of 37 classes, an overall performance of 89.4% (see Table 7) was attained. By comparing Table 4 and Table 6, the reason for improvement of this magnitude becomes apparent. The smallest reduction of variance for hardwood was a factor of 3.2 for Channel 1. The largest reduction in variance was a factor of 25 for Channel 6. Reductions in variance of this order indicate that the location of the cluster centers in the q-variate hyperspace deviated substantially from the actual "regions" of concentration in the data. The cluster centers were assumed to be located somewhere between such regions. A reduction in variance of similar magnitude occurred for tupelo. Smaller reductions occurred in pasture and clearcut. This is probably due to the highly variable states of nature found in conjunction with each of these latter cover classes, resulting in a more general spread in the distributions, with less pronounced concentrations in the data. When working with q-variate hyperspace, univariate histograms and bivariate scatterplots are not optimal but are essentially the only tools available to obtain some insight regarding the data distributions. Much attention was given to training statistics development since the concern in the later analyses will be with differences in classification accuracies achieved with different resolutions.

The persistently low classification accuracy for sycamore is due to: 1) extremely high similarity to second growth hardwoods and 2) the availability of a very small number of training pixels. This class has therefore been merged with second growth hardwood.

Training statistics for each of the spatial resolutions are currently being developed for the spatial resolution evaluation. It is anticipated that results for this part of the study will be available for the next report.

Table 5. Classification Performance Evaluation from Classification of Training Data with 32 Class Training Statistics.

	No. of Pts.	% Correct	Soil	Past	Crop	Pine	Pihd	Hdwd	Sghd	Tupe	Syca	Ccut	Mveg	Tuwa	Mveg	Vewa	Watr
Soil	1946	88.6	1724	0	22	1	2	0	0	0	0	178	9	1	6	2	1
Past	987	24.7	60	244	520	1	0	144	3	0	0	6	6	0	3	0	0
Crop	1445	98.1	6	5	1417	2	1	0	1	0	0	11	1	0	1	0	0
Pine	805	81.4	0	7	0	655	125	14	0	0	0	0	4	0	0	0	0
Pihd	314	89.8	0	0	0	26	282	2	1	0	0	0	2	0	1	0	0
Hdwd	3997	5.1	0	637	1	1	11	202	2301	691	104	41	7	0	0	1	0
Sghd	2242	94.0	0	61	2	0	1	52	2107	9	0	7	1	0	0	2	0
Tupe	350	0.0	0	186	52	0	0	101	4	0	0	0	7	0	0	0	0
Syca	35	0.0	0	11	3	0	0	0	20	0	0	0	1	0	0	0	0
Ccut	4277	17.9	234	2460	40	156	4	508	33	3	28	765	32	0	2	11	1
Mveg	294	98.0	3	0	0	3	0	0	0	0	0	0	288	0	0	0	0
Tuwa	124	99.2	0	0	0	0	0	0	0	0	0	0	0	123	1	0	0
Mveg	66	100.0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0
Vewa	39	97.4	0	0	0	0	0	0	0	0	0	0	0	0	1	38	0
Watr	232	97.0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	225

Overall Classification Accuracy (8136/17153) = 47.4%

ORIGINAL PAGE IS OF POOR QUALITY

Table 6 . Summary of Statdeck Containing 37 Spectral Classes.*

	1	2	3	4	5	6	7
SOIL1	154.87	177.14	149.79	131.14	188.11	189.22	143.31
	243.34	635.95	705.00	320.66	308.40	513.50	767.91
SOIL2	128.42	125.67	128.85	135.62	144.49	144.83	139.44
	88.26	194.42	240.09	223.42	158.03	156.41	1162.87
SOIL3	111.10	95.63	92.60	99.29	109.41	106.21	135.06
	105.86	235.72	308.13	361.95	331.33	396.72	734.38
PAST1	107.48	93.05	81.10	148.14	162.16	131.79	197.08
	9.79	29.30	74.74	151.33	87.59	63.29	283.63
PAST2	104.65	85.95	62.46	188.67	176.23	102.77	145.38
	4.75	9.49	17.70	116.83	34.90	51.15	138.17
PAST3	104.30	85.04	69.62	141.63	148.91	108.70	154.41
	19.73	22.34	52.99	162.09	97.33	68.28	196.43
PAST4	99.52	80.96	58.73	171.73	154.58	84.27	115.33
	8.07	13.68	17.95	222.32	59.75	35.41	58.16
PAST5	97.60	73.76	51.20	165.09	135.90	63.37	87.51
	5.56	7.60	7.15	46.32	30.41	25.85	55.26
CROP1	117.65	111.12	100.67	172.25	161.50	119.68	103.02
	42.54	130.55	309.76	203.03	140.88	229.97	221.09
CROP2	100.77	76.21	52.34	210.17	160.62	68.76	82.34
	5.80	16.76	22.41	176.97	39.00	40.72	40.46
CROP3	99.82	82.30	71.21	118.67	117.97	91.60	137.56
	37.79	37.85	70.78	115.25	118.15	203.40	268.31
CROP4	96.08	76.64	58.46	150.22	127.02	64.76	97.05
	6.16	30.63	45.40	199.89	141.36	70.29	194.62
PINE1	92.26	69.76	54.05	113.46	115.17	71.86	116.23
	3.11	6.35	13.46	81.46	65.40	50.93	288.47
PINE2	94.75	67.90	48.67	118.79	112.27	59.60	83.64
	13.59	8.73	5.99	104.89	83.46	40.22	73.18
PIHD1	91.69	69.46	55.44	109.79	110.61	70.28	127.44
	14.58	8.39	11.85	54.06	46.92	28.53	379.38
PIHD2	94.31	65.79	46.98	112.63	105.95	53.95	84.25
	6.04	7.61	7.09	119.94	35.44	29.96	54.55
HDWD1	92.12	66.21	43.92	161.01	138.32	65.29	78.90
	2.48	4.29	2.64	38.25	20.72	15.45	30.02
HDWD2	91.45	66.07	43.94	146.15	127.10	61.97	77.05
	4.73	11.26	5.93	30.91	16.15	19.43	43.73
HDWD3	94.52	58.21	38.78	124.69	105.22	52.82	72.92
	8.75	7.59	5.89	36.81	55.82	10.90	19.29
SGHD1	91.42	67.31	44.23	175.67	150.73	71.57	84.74
	7.13	9.40	5.47	55.54	38.43	29.82	55.83
SGHD2	86.10	61.11	40.45	155.12	133.78	63.65	81.08
	32.01	20.54	6.09	54.63	29.75	17.06	60.84
SGHD3	91.52	64.64	41.91	131.63	112.29	56.05	65.85
	13.22	9.93	6.45	125.96	92.78	16.65	34.31
TUPE1	95.44	80.55	51.29	193.49	155.89	77.26	80.27
	7.53	12.71	3.64	66.36	30.81	10.74	97.30
TUPE2	95.67	80.57	51.68	164.41	141.59	74.01	81.98
	7.47	12.79	4.47	45.11	36.50	12.20	37.88

Table 6. Summary of Statdeck Containing 37 Spectral Classes (cont'd.).

	1	2	3	4	5	6	7
TUPE3	82.83	72.67	46.51	124.39	109.04	60.90	79.67
	8.41	3.40	0.89	11.67	6.59	1.56	22.23
SYCA1	67.53	66.20	50.40	123.40	124.13	82.37	116.73
	2.98	4.39	13.40	368.97	204.27	11.41	105.64
SYCA2	34.40	60.05	39.70	130.50	115.20	56.95	30.05
	2.15	4.58	7.80	294.47	167.96	28.55	35.84
CCUT1	101.66	33.29	73.24	121.39	135.02	112.71	189.76
	39.09	50.16	145.27	163.30	73.32	123.54	463.75
CCUT2	96.86	76.45	64.94	107.61	114.36	91.23	137.69
	17.11	35.73	117.13	191.87	140.05	98.60	198.27
CCUT3	91.66	70.97	50.25	142.64	131.36	77.78	100.85
	7.20	11.70	19.19	276.54	110.55	44.09	132.54
CCUT4	91.17	66.86	52.46	83.56	83.20	62.04	98.73
	19.28	26.99	75.15	330.60	325.53	164.53	300.15
MVEG1	102.64	79.12	65.10	110.00	123.25	89.91	123.56
	22.73	73.10	174.96	58.84	51.46	102.11	204.00
MVEG2	100.76	76.83	52.67	123.72	112.42	64.49	80.16
	8.90	20.02	14.56	173.99	118.27	66.70	113.35
TUWA1	172.62	195.62	139.18	55.29	37.92	27.02	76.42
	107.95	279.16	79.42	94.48	120.65	95.07	28.94
VEGE1	126.08	114.84	88.24	104.06	95.86	63.05	90.47
	162.80	502.66	336.20	242.38	392.74	204.28	115.30
VFWA1	107.63	32.53	55.08	61.63	57.93	42.91	88.04
	19.90	36.65	27.39	119.81	111.52	59.06	29.35
WATR1	107.08	78.41	52.51	39.08	33.06	24.97	71.62
	43.52	123.32	31.19	13.04	17.75	14.22	143.33

*Within each spectral class, the upper element is the mean and the lower is the variance.

Channel Number	Band
1	0.45 - 0.52
2	0.52 - 0.60
3	0.63 - 0.69
4	0.76 - 0.90
5	1.00 - 1.30
6	1.55 - 1.75
7	10.4 - 12.50

Table 7. Classification Performance Evaluation from Classification of Training Data with 37 Class Training Statistics.

	No. of Pts.	% Correct	Soil	Past	Crop	Pine	Pihd	Hdwd	Sghd	Tupe	Syca	Ccut	Mveg	Tuwa	Vege	Vewa	Watr
Soil	1946	95.3	1855	3	22	1	2	0	0	0	0	46	7	1	6	2	1
Past	987	95.6	5	944	8	0	0	0	1	0	0	29	0	0	0	0	0
Crop	1445	97.0	9	23	1402	2	1	0	1	0	0	5	1	0	1	0	0
Pine	805	81.1	1	0	0	653	124	4	0	0	0	19	4	0	0	0	0
Pihd	314	89.8	0	0	0	26	282	1	0	0	0	2	2	0	1	0	0
Hdwd	3997	87.7	0	3	1	1	10	3507	357	2	37	75	4	0	0	0	0
Sghd	2242	85.1	0	0	2	0	0	307	1907	6	1	16	1	0	0	2	0
Tupe	350	98.9	0	0	0	0	0	2	0	346	0	0	2	0	0	0	0
Syca	35	0.0	0	0	0	0	0	0	20	11	0	3	1	0	0	0	0
Ccut	4277	86.3	147	103	36	107	2	82	22	39	25	3693	15	0	1	4	1
Mveg	294	97.6	3	0	0	2	0	0	0	0	0	2	287	0	0	0	0
Tuwa	124	99.2	0	0	0	0	0	0	0	0	0	0	0	123	1	0	0
Vege	66	100.0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0
Vewa	39	97.4	0	0	0	0	0	0	0	0	0	0	0	0	1	38	0
Watr	232	100.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	232

Overall Classification Accuracy (15335/17153) = 89.4%

II. PROBLEMS ENCOUNTERED

No problems of significance were encountered during the past quarter. Some difficulties were encountered in following the methodology initially established for identification of the cover type in the defined test pixel, thereby causing some delay in the analysis of the 1979 TMS data. However, these problems have been resolved, and the modified methodology currently being used is much faster and should produce test data sets having a higher degree of reliability among the different analysts involved.

III. PERSONNEL STATUS

The following personnel committed the respective percentages of time to the project during the past quarter:

Name	Position	Ave. Monthly Effort (%)
Bartolucci, Luis	Professional Research Analyst	10
Dean, Ellen	Research Associate	100
Frazee, Michael	Research Assistant	50
Hoffer, Roger	Principal Investigator	80
Knowlton, Douglas	Research Associate	50
Latty, Rick	Research Associate	100
Peterson, John	Associate Director	5
Prather, Brenda	Secretary	50
Stiles, Stephanie	Secretary	3

IV. ANTICIPATED ACCOMPLISHMENTS

The following are the anticipated accomplishments of the forthcoming quarter (September 1, 1980 - November 30, 1980):

1) Digitization of the SAR data for Flight Line #1, HH and HV polarizations.

2) Completion of the definition of the test data sets for Study Site 1-N and 2-N.

3) Continuation of the analysis of the four different spatial resolutions of the 1979 data.

4) Continuation of the analysis of the spectral characteristics of the 1979 TMS data.

5) Receipt of the 1980 TMS data and initiation of the reformatting and rectification procedures.

6) Prepare the 18-month report required by this contract.

7) Definition of the Statement-of-Work to be followed during F.Y. '81 and renegotiation of the contract for F.Y. '81.

No major technical problems are anticipated during the forthcoming quarter. Due to (a) an announced plan to significantly decrease the level of funding on this contract during F.Y. '81, and (b) the delays in obtaining, and characteristics of the TMS and SAR data obtained in support of this project, it is anticipated that the objectives initially proposed will need to be modified. These modifications will be reflected in the Statement-of-Work which will be developed during this next quarter.

References Cited

Greer, J.D., "Ground Dimension from Slant/Range Radar," Photogrammetric Engr. and Rem. Sens., Aug., 1975.

Tomiyasu, K., "Tutorial Review of Synthetic-Aperature Radar (SAR) with Applications to Imaging of the Ocean Surface," Proc. IEEE, Vol. 66; 5 May 1978.

Swain, P.H., "Fundamentals of Pattern Recognition in Remote Sensing," in Remote Sensing: The Quantitative Approach, ed. by P.H. Swain and S.M. Davis. McGraw-Hill Inter. Book Co., pp. 136-185.

Wiersma, D.J. and D.A. Landgrebe, "An Analytical Approach to the Design of Spectral Measurements in the Design of Multispectral Sensors," 1979 Mach. Proc. of Remotely Sensed Data Symp. pp. 331-341.

APPENDIX A

Paper entitled "Waveband Evaluation of Proposed Thematic Mapper in Forest Cover Classification," by R. S. Latty and R. M. Hoffer, to be presented at the 1980 Fall Technical Convention of the American Society of Photogrammetry, to be held in Niagara Falls, New York.

WAVEBAND EVALUATION OF PROPOSED THEMATIC MAPPER IN FOREST COVER CLASSIFICATION

Richard S. Latty and Roger M. Hoffer
Purdue University
West Lafayette, Indiana 479

ABSTRACT

This study involved the evaluation of the characteristics of multispectral scanner data relative to forest cover type mapping, using NASA's NS-001 multispectral scanner to simulate the proposed Thematic Mapper (TM). The objectives were to determine: (1) the optimum number of wavebands to utilize in computer classifications of TM data; (2) which channel combinations provide the highest expected classification accuracy; and (3) the relative merit of each channel in the context of the cover classes examined. Transformed divergence was used as a measure of statistical distance between spectral class densities associated with each of twelve cover classes. The maximum overall mean pair-wise transformed divergence was used as the basis for evaluating all possible waveband combinations available for use in computer-assisted forest cover classifications.

INTRODUCTION

Early work in leaf spectra analysis (Billings and Morris, 1951; Gates and Tantraporn, 1952; Gates, et al., 1965; Gausman, et al., 1969; Knipling, 1970; Wooley, 1971; Gausman, 1977) provided much of the initial understanding of the variations in the amount of radiant energy returned from vegetated surfaces. Colwell (1974) identified the value of hemispheric leaf reflectance as only one of several important parameters responsible for these variations, and cautioned against making inferences about scene reflectance from leaf spectra information alone. Plant canopy modeling efforts (Idso and De Wit, 1970; Nilson, 1971; Oliver and Smith, 1972; Suits, 1972; Colwell, 1973) have identified many of the parameters which account for variations in the amount of radiant energy returned from the scene. The selection of waveband combinations which will provide accurate classification of the various earth surface features requires an understanding of the reflective characteristics of those features relative to the various wavebands available. Properties of the data consequential to classification accuracy are not dependent solely on earth surface, atmospheric, and illumination conditions. They are also very dependent on the parameters of the sensor system to be employed (Silva, 1978). Therefore, the need exists to investigate these reflective properties employing data more closely simulating the data which will ultimately be employed for such classifications.

With parametric classifiers, the resulting classification accuracy is dependent on (1) the degree to which the

training classes (i.e., spectral classes) represent the spectral variability of their respective cover classes, and (2) the level of statistical "separability" among the training classes (Swain, 1978). The first condition is difficult if not impossible to assess without conducting the actual classification - the expense of which precludes evaluating many different waveband combinations. One can justifiably assume that the first condition is satisfied if the points providing the data for establishing the training classes are randomly generated, and are "sufficient" in number for each class relative to the number of wavebands employed. The number of samples statistically sufficient for the development of training classes increases exponentially with an increase in the number of channels employed in classification (Duda and Hart; 1973). Duda and Hart (1973) pointed out that, "beyond a certain point, the inclusion of additional features leads to worse rather than better performance." They provide an excellent review of the problem. This problem has also been examined by Allais (1966), Dynkin (1961), Fukunaga and Kessell (1971), Kanal and Chandrasekaran (1971) and others. The level of statistical "separability" can be computed from the mean vectors and covariance matrices associated with each of the training classes employing one of several statistical distance measures (Kailath, 1967; Swain, Robertson and Wacker, 1971; Wacker and Landgrebe, 1972; King and Swain, 1973).

METHODS AND ANALYSIS

Data Acquisition

The data were obtained on May 2, 1979 from the NASA NC-130 aircraft flying at an altitude of 20,000 ft. (MGD) over an area immediately south of Camden, South Carolina. The multispectral scanner (MSS) data were obtained by the NASA NS-001 multispectral scanner. (Table 1 shows the NS-001 scanner specifications as compared to the Thematic Mapper). Color and color infrared photographs (1:40,000 scale transparencies) were obtained at the same time. Cloud coverage was minimal and atmospheric conditions were considered excellent.

Data Handling and Preprocessing

The across track change in scale of the imagery was adequately reduced by employing a geometric model which describes the ground resolution element dimensions as a function of aircraft altitude, IFOV (instantaneous field-of-view) of the scanner, and change in scan angle corresponding to the analog signal integration interval.

A study of the data quality revealed an apparent correlation between scan angle and response level (different for each channel). The relationships appeared to be sufficiently high to obscure sources of variation otherwise correlated with differences between cover classes. Therefore, an empirically derived function was generated which described the variation in response level by column (corresponding with scan angle). Data were employed from areas where no

ORIGINAL PAGE IS
OF POOR QUALITY

apparent stratification of cover class by column was present.* The shape of these functions were evaluated against both empirical (Anuta and Strahorn, 1973; Landgrebe, Beihl, and Simmons, 1977) and theoretical work (Kondratyev, 1969; Jurica and Murray, 1973) prior to actual response level adjustment. The final data product was considered appropriate for the analysis.

Table 1. Comparison of the NASA NS-001 multispectral scanner and the proposed Thematic Mapper (TM).

NS-001 Multispectral Scanner[1]				Proposed Thematic Mapper[2]			
Channel	Bandwidth (μm)	Low Level Input ($W \cdot CM^{-2} \cdot SR^{-1}$)	NE$\Delta\rho$	Channel	Bandwidth (μm)	Low Level Input ($W \cdot CM^{-2} \cdot SR^{-1}$)	NE$\Delta\rho$
1	0.45-0.52	0.7×10^{-6}	0.5%	1	0.45-0.52	2.8×10^{-4}	0.8%
2	0.52-0.60	6.8×10^{-6}	0.5%	2	0.52-0.60	2.4×10^{-4}	0.5%
3	0.63-0.69	5.0×10^{-6}	0.5%	3	0.63-0.69	1.3×10^{-4}	0.5%
4	0.76-0.90	4.4×10^{-6}	0.5%	4	0.76-0.90	1.6×10^{-4}	0.5%
5	1.00-1.30	6.0×10^{-6}	1.0%				
6	1.55-1.75	6.2×10^{-6}	1.0%	5	1.55-1.75	8.0×10^{-5}	1.0%
7[3]	2.08-2.35	4.7×10^{-5}	2.0%	6	2.08-2.35	5.0×10^{-5}	2.4%
8	10.4-12.5	NA	NEΔT=0.25°K	7	10.4-12.5	300°K	NEΔT=0.5°K

[1] Data was obtained from the "Operations Manual, NS-001 Multispectral Scanner," NASA; JSC-12715, April 1977.

[2] Data was obtained from Salomonson, 1978.

[3] Channel 7 (2.08-2.35 μm) was not operational at the time of the mission; all subsequent references to "channel 7" refer to the 10.4-12.5 μm waveband.

Development of Spectral Classes

A COMTAL Vision One/20, displaying a composite of channels 3, 4, and 5, in conjunction with the aerial photography, was employed to ascribe cover class labels and ground condition descriptions to line-column coordinates in the imagery in a supervised fashion. This approach was considered more appropriate than the unsupervised clustering approach, since cover classes could be defined more nearly independent of their spectral characteristics in the wavebands to be evaluated. The method used to develop training classes was of particular concern since the affect of different within-class variances for each channel by cover class on cluster class composition is not currently well understood (Bartolucci, 1978; Anuta, 1979). Once the training fields had been identified, they were grouped according to cover class. The cover class groups of training fields were then individually clustered to resolve the cover classes into a set of spectral classes. This provided training class statistics corresponding to a set of spectral classes associated with each cover class. Clustering at this stage provided a means of

*The function was generated using data obtained outside of the area from which the data for this analysis was obtained.

establishing the spectral classes on the basis of spectral variability within each cover class, but did not completely avoid the problem mentioned above. Failure to provide training statistics representing the spectral variability within each cover class was considered more deleterious to the objective of the study than clustering to obtain those classes.

Data Analysis

The mean vector and covariance matrix computed for each of the spectral classes define the individual statistical density associated with each respective spectral class. A measure of statistical distance between all pair-wise combinations of the spectral classes provides information on the "separability" of these spectral classes. This "separability" represents an *a priori* estimate of the probability of correct classification (Swain, Robertson, and Wacker, 1971) for measurements provided by each channel or channel combination. Only pairs of spectral classes belonging to different cover classes are of interest, since low separability between different spectral classes of the same cover class does not affect classification accuracy.

Transformed divergence was used to compute the separability. Divergence is defined as:

$$D = \int [p_1(x) - p_2(x)] \ \ln \frac{p_1(x)}{p_2(x)} \, dx \tag{1}$$

where: $p_1(x)$ = statistical density of spectral class 1

$p_2(x)$ = statistical density of spectral class 2

or computationally, for the Gausian multivariate case:

$$D = \frac{1}{2} \operatorname{tr} [(\Sigma_1 - \Sigma_2)(\Sigma_1^{-1} - \Sigma_2^{-1})] + \frac{1}{2} \operatorname{tr} [(\Sigma_1^{-1} + \Sigma_2^{-1})(m_1 - m_2)(m_1 - m_2)^T] \tag{2}$$

where: Σ is the covariance matrix and m is the mean vector associated with the respective spectral class, and

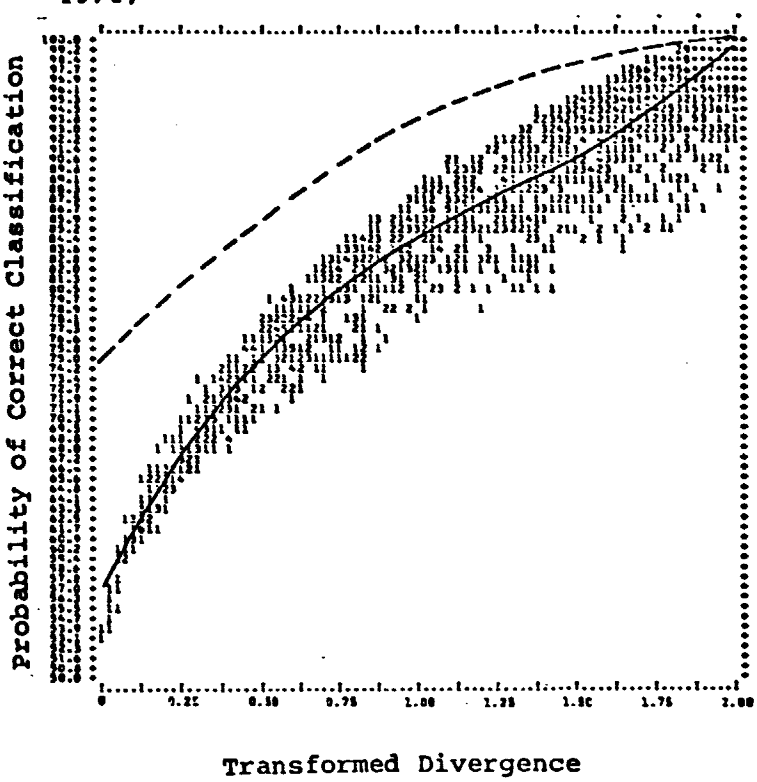
tr (trace) is the sum of the diagonal elements.

Since divergence increases without bound as the statistical distance between the two classes increases, a saturation transform is employed, resulting in a measure (i.e., transformed divergence) which corresponds more closely with percent correct classification (see Figure 1). After a certain level of statistical difference has been attained, virtually no confusion exists between the two class densities, and percent correct classification "saturates" toward 100%. The resulting transformed divergence is provided by:

$$TD = 2000 \, [1 - \exp(-D/8)] \tag{3}$$

There are some disadvantages to the use of transformed divergence as a measure of statistical difference between class densities*, but because of relative computational efficiency it is used in lieu of the alternative measures.

Figure 1. Probability of correct classification regressed against transformed divergence. (Swain et al., 1971)



Transformed divergence (TD) values were computed for each pair of spectral classes representing different cover classes, for each channel and channel combination. These mean pair-wise TD-values were then sorted for each set of combinations involving the same number of channels. The seven channel combinations providing the highest mean pair-wise TD-values were obtained. Additional programs were written to generate summaries of the mean TD-values for each pair of cover classes (i.e., over all spectral classes representing the cover class pair) and each cover class

---

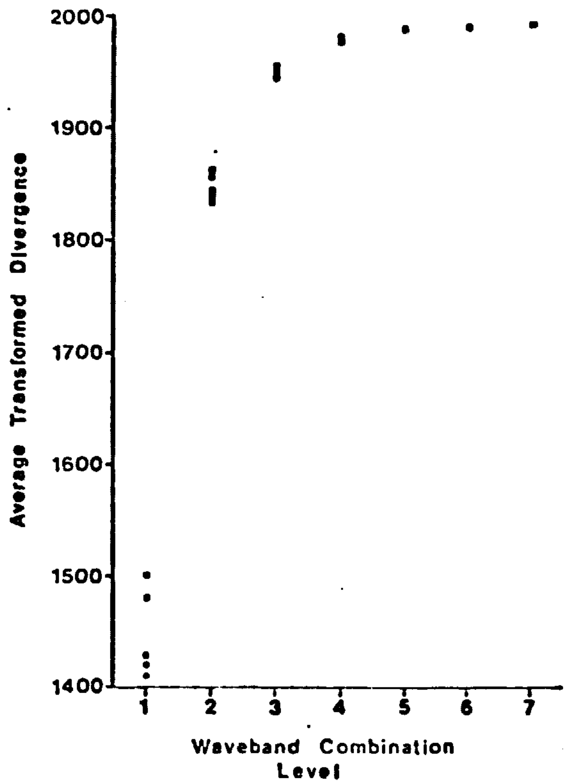
*It should be pointed out that transformed divergence is not "metric" in multivariate normal distribution functions of non-equivalent covariance matrices (Landgrebe and Wacker; 1972). That is, a pair of class densities having non-equivalent covariance matricies yet having equal mean vectors could have a transformed divergence value of zero. Also, there is no estimate for a lower confidence limit for the regression relation between transformed divergence and percent correct classification (Swain, Robertson, and Wacker; 1971).

(i.e., over all cover class pairs involving the jth cover class; j = 1,...,12) for these seven channel combinations.

RESULTS AND DISCUSSION

To define the optimum number of channels to use in a classification, the relationship between cost of misclassification and the probability of error must be determined. Otherwise there is no meaningful way to compare classification cost to classification accuracy. It can be observed from Figure 2 that the increase in transformed divergence (the correlate to probability of correct classification) drops off sharply after three channels, and very little is gained by using more than four channels. This result is similar to those obtained previously with the Michigan M-7, 12-channel scanner (Coggeshall and Hoffer, 1973), and the skylab 13-channel S-192 scanner (Hoffer et al., 1975). The shape of the relationship shown in Fig. 2 indicates that transformed divergence increases logarithmically as the combination level increases linearly*. The spread of the points representing the five highest ranked channel combinations for each combination level represents the difference between

Figure 2. Averaged transformed divergence for the best five waveband combinations for each combination level.



*To simplify the following discussions, "combination level" will refer to the number of channels involved in any particular set of channel combinations.

successively ranked averaged transformed divergence. As seen in Fig. 2, the mean difference between successively ranked mean separabilities decreases logarithmically as the combination level increases linearly. This implies that the rank of overall mean separability as a feature selection criterion decreases in value as the number of features comprising the selected feature subset increases.

The best combined sources of information for distinguishing between various cover classes need not have as a subset the best single source of information. This is indicated in Table 2, which shows, for example, that the single channel having the highest mean TD-value (i.e., channel 6) is not included in the 2, 3, and 4 channel combination levels having the highest mean TD-values. By comparing Table 2 with Table 3, it can be observed that the best channel or channel combination for each combination level, on the basis of mean overall separability, is not necessarily superior on a per cover class basis.

Table 2. Channel combinations, ranked by overall mean TD-value for combination levels one through six.

COMBINATION LEVEL					
1	2	3	4	5	6
6	3,4	3,4,5	1,3,4,5	1,3,4,5,6	1,2,3,4,5,6
3	3,5	3,4,6	3,4,5,6	2,3,4,5,6	2,3,4,5,6,7
1	2,4	3,5,6	1,3,4,6	1,2,3,4,5	1,3,4,5-6,7
5	2,5	2,4,5	3,4,5,7	1,3,4,5,7	1,2,3,4,6,7
2	3,6	2,4,6	2,4,5,7	3,4,5,6,7	1,2,4,5,6,7
4	4,6	2,5,6	2,3,4,6	2,4,5,6,7	1,2,3,4,5,7
7	1,4	1,3,4	1,3,5,6	1,2,3,5,6	1,2,3,4,6,7

Table 3. Best channels and channel combinations by TD-value for each cover class. TD-value is in parentheses.

	COMBINATION LEVEL			
	1	2	3	4
soil	3(1820)	24(1941)	256(1987)	1346,2346,1356(1992)
past	6(1476)	35(1878)	345(1971)	3457(1987)
crop	3(1390)	34(1836)	345(1971)	1345(1991)
pine	2(1435)	34(1780)	346(1912)	3456(1960)
pihd	2(1580)	36(1883)	356(1982)	3456(1997)
hdwd	3(1688)	34(1881)	134(1933)	2346(1952)
sghd	3(1691)	35(1933)	346(1960)	1345,1346,2346(1972)
tupe	6(1658)	34(1896)	245,345(1979)	2457(1992)
syca	5(1753)	35(1979)	345(1994)	1345,1346,1356(1999)
ccut	6(1329)	46(1707)	356(1889)	3456(1947)
mveg	4(1270)	14(1739)	134(1941)	1345(1990)
watr	5(1853)	25(1988)	246,256(1999)	1345,1346,1356(2000)

SOIL, bare soil; PAST, pasture; CROP, row and cereal crops; PINE, pine forest; PIHD, pine-hardwood mix; HDWD, old age hardwood; SGHD, second growth hardwood; TUPE, water tupelo; SYCA, sycamore hardwood; CCUT, clearcut areas; MVEG, marsh vegetation; WATR, river water and quarry water.

Examination of the transformed divergence averaged for each cover class pair indicated that the proper selection of a single channel may provide greater separability between two cover classes than a combination of two or three channels. More specifically, the channel combination with the highest mean separability for a particular combination level does not necessarily provide a greater separability for all cover class pairs than channel combinations of a lower combination level, when the combination of the lower level is not a subset of the combination of the higher level. Examples of this relationship are: soil vs. water has a mean TD-value of 1942 in channel 6 and a mean TD-value of 1824 in channel combination 3,4; PIHD vs. CCUT has a mean TD-value of 1835 in channel 6 and a mean TD-value of 1641 in channel combination 3,4; PINE vs. MVEG has a mean TD-value of 1424 in channel 1 (the channel ranked third on the basis of mean overall TD-value) and the mean TD-value of 1182 in channel combination 3,4 (the number one ranked channel combination of all combinations involving two channels). The same relationship holds for many other cover class pairs. Such a relationship was not found when the lower level channel combination was a subset of the higher level channel combination (as would be expected).

The additional average separability achieved for each cover class, by increasing the combination level, varies greatly between cover classes and combination levels, but generally decreases logarithmically with increasing combination level. Figure 3 can be thought of as a "separability response surface." The apparent length of the lines connecting different combination levels of the same cover class is proportional to the added separability resulting from the information in the additional channel. Note that the greatest increase in separability due to the addition of the second channel occurs with second growth hardwood. As one would expect, the smallest increase in separability occurs with that cover class with the highest single channel separability (soil, in this case). It should be noted that the lines connecting the different cover classes are present merely to indicate relative differences of separability and in no way imply any functional relationship.

Figure 3 plots the maximum transformed divergence observed for each cover class in each combination level. This displays the maximum separability attainable for each cover class if the waveband combinations were selected on the basis of each cover class TD-value alone. As is clearly shown, the specific waveband combination resulting in each particular TD-value for any given waveband combination level is not constant over the different cover classes. In comparing Figures 3 and 4, it is apparent that the shapes of the curves increase in similarity with an increase in waveband combination level and are nearly identical in shape after combination level 4. This indicates that the separability by cover class provided by the best overall channel combination (Fig. 3) is nearly identical to the separability by cover class provided by the best channel combination for each individual cover class (Fig. 4) beyond waveband combination levels of 4. Thus, the best four waveband combination, based on overall transformed divergence, should provide very

close to the maximum classification accuracy for each individual cover type. However, if one were interested only in a particular cover type, high classification accuracy could be achieved using less than four channels of data.

Figure 3. Averaged transformed divergence provided by the overall best waveband combination by waveband combination level and cover class.

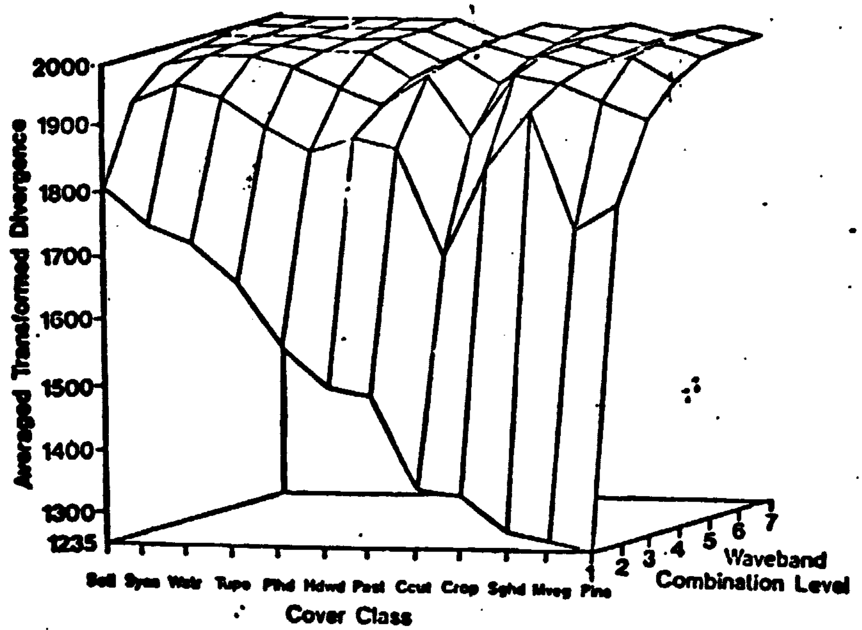
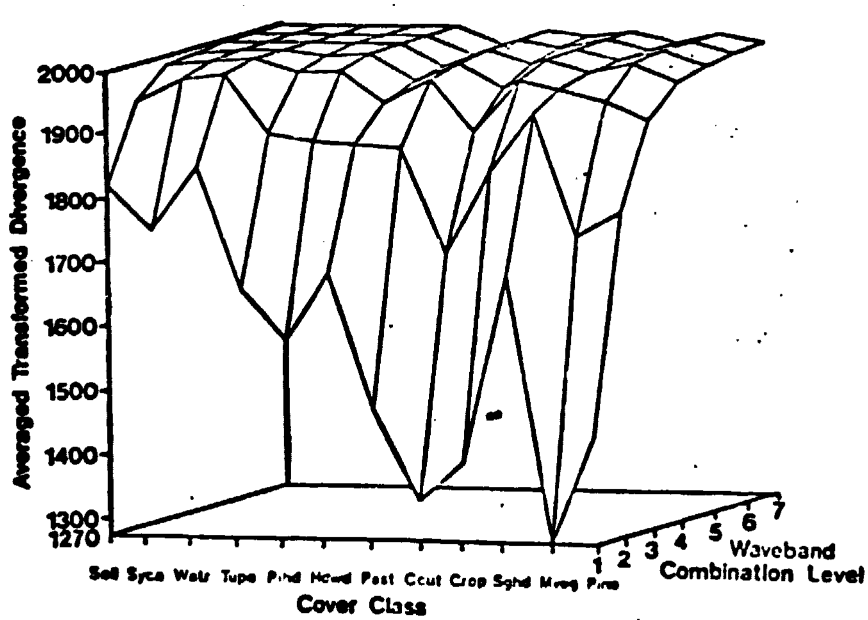


Figure 4. Averaged transformed divergence provided by the best waveband combination for each cover class by waveband combination level and cover class.



SUMMARY AND CONCLUSIONS

Based upon the results of this study, one would not expect a computer-based classification employing more than four channels to provide much improvement in classification accuracy. The highest overall mean separability was provided by channels 1, 3, 4, and 5 (0.45-0.52, 0.63-0.69, 0.76-0.90, and 1.0-1.3 μm). This channel combination did not always provide the highest mean separability by cover class nor by pairs of cover classes. A different set of cover classes, or even a subset of the cover classes considered in this work, could result in other channel combinations yielding higher predicted classification accuracies.

Results such as these are highly data and application dependent. The conclusions pertain to channel subsets selected for classification and in no way imply that scanner systems need only obtain data in those channels in order to adequately provide remote sensory data to the various disciplines. Similar studies involving different cover classes and different seasons need to be conducted along with follow-up studies involving actual classifications.

ACKNOWLEDGEMENTS

This work was supported by NASA Contract NAS9-15889, NASA Johnson Space Center, Houston, Texas.

REFERENCES

Anuta, P.E. and D.F. Strahorn. 1973. "Sun Angle Effect Preprocessing with Predicted Ramp Functions." LARS Technical Memorandum T-12.

Anuta, P.E. and Nim-Yau Chu. 1979. "Multidimensional Scaling for Clustering of Dissimilar Data Type." LARS Information Note, prepared for NSF, grant #ENG-7614400. 27 pp.

Bartolucci, L.A. and R.B. de Castro. 1979. "Clustering of Landsat MSS Data: Certain Limitations." LARS Technical Report.

Billings, W.D. and R.J. Morris. 1951. "Reflection of Visible and Infrared Radiation from Leaves of Different Ecological Groups." American Journal of Botany, Vol. 38, May 1951. pp. 327-331.

Colwell, J.E. 1973. "Bidirectional Reflectance of Grass Canopies for Determination of Above Ground Standing Biomass." Ph.D. dissertation. University of Michigan, Ann Arbor, Michigan.

Colwell, J.E. 1974. "Vegetation Canopy Reflectance." Remote Sensing of Environment, 3. pp. 175-183.

ORIGINAL PAGE IS
OF POOR QUALITY

Dynkin, E.B. 1961. "Necessary and Sufficient Statistics for a Family of Probability Distributions." In Selected Translations in Mathematical Statistics and Probability. Vol. 1. pp. 17-39.

Duda, R.O. and P.E. Hart. 1973. "Pattern Classification and Scene Analysis." John Wiley & Sons, New York. 482 p.

Fukunaga, K. and D.L. Kessel. 1971. "Estimation of Classification Error." IEEE Trans. on Computers. Vol. 20:12. pp. 1521-1527.

Gates, D.M., H.J. Keegan, J.C. Schleter and V.R. Weidner. 1965. "Spectral Properties of Plants." Applied Optics, Vol. 4, No. 1. Jan. 1965. pp. 11-20.

Gates, D.M. and W. Tantraporn. 1952. "The Reflectivity of Deciduous Trees and Herbaceous Plants in the Infrared to 25 Microns." Science, 115. pp. 613-616.

Gausman, H.W., W.A. Allen and R. Cadenas. 1969. "Reflectance of Cotton Leaves and Their Structure." Remote Sensing of Environment, Vol. 1. pp. 19-22.

Gausman, H.W. 1977. "Reflectance of Leaf Components." Remote Sensing of Environment, Vol. 6. pp. 1-9.

Hoffer, R.M., R.E. Joosten, R.G. Davis and F.R. Brumbaugh. 1978. "Land Use and Cartography." Chapter 2 in: Skylab EREP Investigations Summary. NASA SP-399. National Aeronautics and Space Administration, Washington, D.C. pp. 7-77.

Idso, S.B. and C.T. de Wit. 1970. "Light Relations in Plant Canopies." Applied Optics, Vol. 9, No. 1. pp. 177-184.

Jurica, G.M. and W.L. Murray. 1973. "The Atmospheric Effect in Remote Sensing of Earth Surface Reflectivities." LARS Info ation Note.

Kailath, T. 1967. "The Divergence and Bhattochargga Distance Measures in Signal Selection." IEEE Trans. Comm. Tech., Vol. 15:7. pp. 52-60.

Kanal, L. and B. Chandrasekaran. 1971. "On Dimensionality and Sample Size in Statistical Pattern Classification." In Pattern Recognition, Pergamon Press, Vol. 3. pp. 225-234.

Knipling, E.B. 1970. "Physical and Physiological Basis for the Reflectance of Visible and Near-IR Radiation from Vegetation." Remote Sensing of Environment, Vol. 1. pp. 155-159.

Kondratyev, K.Y.A. 1969. "Radiation in the Atmosphere." Academic Press. 912 pp.

 ORIGINAL PAGE IS OF POOR QUALITY

Landgrebe, D.A., L. Beihl and W. Simmons. 1977. "An Empirical Study of Scanner System Parameters." IEE Transactions on Geoscience Electronics, Vol. GE-15, No. 3. pp. 120-130.

Nilson, T. 1970. "A Theoretical Analysis of the Frequency of Gaps in Plant Stands." Agricultural Meteorology, Vol. 8. pp. 25-38.

Salomonson, V.V. 1978. "Landsat-D Systems Overview." Proc. of the 12th Inter. Symp. on Rem. Sens. of the Environ. pp. 371-385.

Silva, L.F. 1978. "Radiation and Instrumentation in Remote Sensing." In Remote Sensing: The Quantitative Approach, McGraw-Hill Inter. Book Co., N.Y. pp. 21-133.

Smith, J.A. and R.E. Oliver. 1972. "Plant Canopy Models for Simulating Composite Scene Spetroradiance in the 0.4 to 1.05 Micrometer Region." Proc. of the 8th Symp. on Remote Sensing of the Environ. pp. 1333-1353.

Suits, G.H. 1972. "The Calculation of the Directional Reflectance of a Vegetative Canopy." Remote Sensing of Environment, No. 2. pp. 117-125.

Swain, P.H. "Fundamentals of Pattern Recognition in Remote Sensing." In Remote Sensing: The Quantitative Approach, McGraw-Hill Inter. Book Co. pp. 136-185.

Swain, P.H., T.V. Robertson and A.G. Wacker. 1971. "Comparison of the Divergence and B-distance in Feature Selection." LARS Information Note. 12 pp.

Swain, P.H. and R.C. King. 1973. "Two Effective Feature Selection Criteria for Multispectral Remote Sensing." LARS Information Note. 5 pp.

Wacker, A.G. and D.A. Landgrebe. 1972. "Minimum Distance Classification in Remote Sensing." LARS Print. 25 pp.

Wooley, J.T. 1971. "Reflectance and Transmittance of Light by Leaves." Plant Physiology 47:656-662.

Appendix B - Computer Programs Developed

The following is a list of some of the programs written during the quarter June 1, 1980 - August 31, 1980. A brief description is included to assist those in need of similar code.

WGHT2 FORTRAN - Reads a file containing: 1) number of the cover classes to which a spectral class belongs, and 2) the number of pixels from each spectral class. It then computes a weight for each spectral class pair and writes a disk file of "WEIGHTS" cards within the restrictions of *SEPARABILITY. Another disk file of real variable probabilities for the occurrence of each spectral class, and the conditional probability of the occurrence of the spectral class given the occurrence of the cover class of which it is a subset.

GRID·FTN - A FORTRAN program written for the PDP-11/34 to generate a user specified grid for use in systematic sample selection on the COMTAL Vision one/20.

DIVPRT FORTRAN - A modified version of the DIVPRT subroutine called in *SEPARABILITY which is the printer output supervisor. This was modified to write out the class symbols and separability for each channel combination and each channel combination level, for each spectral class pair.

SPECSEP FORTRAN - Reads the disk file created by the modified DIVPRT and computes the averaged transformed divergence by cover class pair. It also sorts for and prints out the minimum TD value.

SUMG FORTRAN - Reads the disk file created by the modified DIVPRT and computes the averaged transformed divergence by cover class (i.e., for each cover class over all cover class pairs - it uses the original TD_{ij}'s in order to avoid excessive rounding errors).

CAGEN2 FORTRAN - Reads a deck of COMTAL image coordinates and field descriptions; queries the user for the line-column coordinate of the first pixel displayed in terms of MIST coordinates; the run number desired on the output file; and pixel averaging if any. It then computes the MIST coordinates for each field and creates a disk file of LARS-12 card formatted records.

APPENDIX C

Tables of Averaged Transformed Divergence by Cover Class Pairs (generated by SPECSUP FORTRAN) and by cover Class (generated by SUMG FORTRAN).

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-1. Averaged and Minimum Transformed Divergence Values for Single Channels by Cover Class Pair.

Averaged

			Channels						
			6	3	1	5	2	4	7
SOIL	VS	PAST	1556	1994	1798	1240	1845	1255	1152
SOIL	VS	CROP	1525	1572	1546	966	1575	1093	1251
SOIL	VS	PINE	1987	2000	1947	884	2000	578	1345
SOIL	VS	PIHD	2000	2000	1997	1656	2000	1154	1939
SOIL	VS	HDWD	2000	2000	2000	1197	2000	986	1997
SOIL	VS	SGHD	1994	2000	1999	1151	2000	1553	1351
SOIL	VS	TUPE	2000	2000	1994	1453	1988	1548	1959
SOIL	VS	SYCA	2000	2000	2000	1696	2000	1816	1993
SOIL	VS	CCUT	1521	1757	1786	596	1788	478	930
SOIL	VS	MVEG	1761	1749	1661	992	1706	765	1254
SOIL	VS	WATR	1942	1520	1056	1726	1236	1588	1870
PAST	VS	CROP	1183	995	872	1141	910	1067	1193
PAST	VS	PINE	1385	1208	1428	1693	1657	1481	1310
PAST	VS	PIHD	1636	1393	1134	1980	1757	1778	1413
PAST	VS	HDWD	1624	1907	1816	1543	1874	1185	1711
PAST	VS	SGHD	1372	1894	1786	978	1830	866	1452
PAST	VS	TUPE	1683	1624	1447	1341	978	1230	1556
PAST	VS	SYCA	1575	1651	1350	1296	952	1422	1517
PAST	VS	CCUT	1171	966	1147	1407	1059	1310	1194
PAST	VS	MVEG	1107	918	378	1656	676	1689	1222
PAST	VS	WATR	1812	1256	1409	1982	1350	1941	1525
CROP	VS	PINE	974	1281	1226	1001	1557	1156	926
CROP	VS	PIHD	1536	1512	1122	1509	1755	1446	791
CROP	VS	HDWD	1438	1920	1676	1182	1815	1145	1436
CROP	VS	SGHD	962	1998	1654	1093	1736	1257	925
CROP	VS	TUPE	1635	1755	1354	1348	1011	1372	1129
CROP	VS	SYCA	1713	1914	1325	1513	772	1455	1137
CROP	VS	CCUT	881	875	978	990	828	1127	924
CROP	VS	MVEG	857	853	675	1037	555	1302	905
CROP	VS	WATR	1600	1199	1397	1851	1206	1849	1032
PINE	VS	PIHD	962	645	746	957	558	740	865
PINE	VS	HDWD	790	1161	771	574	862	808	1054
PINE	VS	SGHD	372	1229	955	1331	896	1673	1365
PINE	VS	TUPE	1408	1257	1031	1514	1387	1601	1005
PINE	VS	SYCA	1752	1659	1597	1982	1621	1948	1220
PINE	VS	CCUT	1197	963	455	483	823	551	1040
PINE	VS	MVEG	836	1059	1424	185	1458	429	851
PINE	VS	WATR	1451	1249	1900	1667	1886	1599	979
PIHD	VS	HDWD	735	1199	1416	1044	1090	1105	704
PIHD	VS	SGHD	1055	1250	1510	1638	1154	1831	63
PIHD	VS	TUPE	1630	991	1226	1556	1487	1558	257
PIHD	VS	SYCA	1937	1137	967	1999	1605	1997	172
PIHD	VS	CCUT	1935	1137	1005	1467	1260	1153	1259
PIHD	VS	MVEG	1451	1272	1209	949	1725	556	867
PIHD	VS	WATR	1709	1445	1898	1923	1967	1704	358
HDWD	VS	SGHD	887	517	735	1112	670	1132	727
HDWD	VS	TUPE	1633	1655	1029	1391	1816	1344	325
HDWD	VS	SYCA	1979	1921	1879	1965	1895	1897	590
HDWD	VS	CCUT	1787	1712	971	851	1411	897	1831
HDWD	VS	MVEG	1364	1550	1856	586	1709	960	1215
HDWD	VS	WATR	1656	1993	1993	1821	1947	1820	576
SGHD	VS	TUPE	1276	1707	970	1285	1760	1379	250
SGHD	VS	SYCA	1772	1932	1927	1715	1844	1623	96
SGHD	VS	CCUT	1232	1718	1035	1056	1216	1481	1368
SGHD	VS	MVEG	973	1838	1774	1211	1650	1842	1034
SGHD	VS	WATR	1595	1865	1973	1979	1896	1994	393
TUPE	VS	SYCA	1400	1017	1356	1686	629	1578	156
TUPE	VS	CCUT	1522	1541	993	1571	927	1704	1517
TUPE	VS	MVEG	1640	1552	1397	1589	826	1608	1044
TUPE	VS	WATR	1948	1678	1992	1984	1566	1965	440
SYCA	VS	CCUT	1312	1596	1737	1921	975	1902	1609
SYCA	VS	MVEG	1640	1663	1637	1967	508	1989	1136
SYCA	VS	WATR	1993	1395	1998	2000	1565	1999	474
CCUT	VS	MVEG	710	729	964	569	451	750	989
CCUT	VS	WATR	1642	1064	1621	1641	1305	1537	1435
MVEG	VS	WATR	1514	1063	1232	1740	1068	1581	1 11

ORIGINAL PAGE IS OF POOR QUALITY

Table C-1. Averaged and Minimum Transformed Divergence Values for Single Channels by Cover Class Pair (cont'd.).

Minimum

Channels

6	3	1	5	2	4	7
112	1139	1022	453	1167	182	374
121	11	39	143	69	102	76
1926	2000	1947	88	2000	135	186
2000	2000	1991	1004	2000	215	1542
2000	2000	1999	266	2000	122	1965
1963	2000	1996	366	2000	771	1863
2000	2000	1977	420	1963	409	1851
2000	2000	2000	734	2000	970	1969
292	1045	1157	23	1222	4	91
900	984	1081	227	1064	9	17
1372	89	190	251	118	59	1388
40	72	50	139	15	2	121
185	197	569	1291	623	168	437
23	32	31	1240	454	602	54
7	1404	1224	127	1205	224	465
12	1287	1161	133	1028	171	21
785	46	169	43	4	40	170
230	612	240	448	332	0	92
257	148	462	319	222	31	275
125	119	47	836	201	492	234
528	169	76	1766	145	1247	53
19	81	261	18	1108	52	137
276	140	236	204	1100	274	8
216	1556	796	239	1394	78	139
12	1330	773	322	1130	134	16
633	566	16	327	26	32	43
1006	1649	428	136	169	469	21
323	30	75	61	98	80	45
1	53	6	50	2	94	139
151	2	452	849	15	359	114
191	140	237	246	66	295	362
234	190	7	159	2	330	113
9	95	138	891	8	1128	340
432	338	147	1109	626	1305	172
1455	1492	1356	1936	1478	1792	536
248	187	84	188	144	73	342
198	17	1007	57	1151	62	103
460	94	1543	481	1671	301	90
11	218	315	713	261	29	186
23	269	651	740	440	1386	2
1026	159	338	1199	325	569	39
1966	843	262	1996	1368	1989	24
1381	40	466	674	145	629	355
255	62	272	80	1161	80	114
880	161	1588	1665	1661	628	22
3	23	83	9	19	96	193
1231	1068	82	684	1417	589	67
1946	1823	1710	1859	1772	1600	237
1236	1139	49	86	534	335	1405
196	1548	1710	128	1445	64	175
795	1548	1979	809	1740	772	25
469	1264	91	25	1306	76	31
1540	1847	1799	948	1657	588	43
337	931	16	150	360	625	773
156	1367	1547	377	1205	1500	33
536	1315	1880	1882	1497	1957	9
737	493	631	742	263	316	120
214	356	358	725	353	1030	846
1179	263	558	1344	235	1113	27
1559	630	1577	1881	197	1939	110
631	1170	1557	1719	669	1622	1069
1123	1319	1114	1968	158	1955	254
1953	1691	1991	1997	754	1994	119
320	3	326	288	40	400	577
579	82	577	140	54	38	209

ORIGINAL PAGE IS OF POOR QUALITY

Table C-2. Averaged and Minimum Transformed Divergence Values for Each of Best 2-Channel Combinations by Cover Class Pair.

Averaged

	Channels 3,4	3,5	2,4	2,5	3,6	4,6	1,4
SOIL VS PAST	1961	1980	1965	1984	1967	1860	1935
SOIL VS CROP	1913	1835	1922	1614	1640	1897	1800
SOIL VS PINE	2000	2000	2000	2000	2000	1994	1995
SOIL VS PIHD	2000	2000	2000	2000	2000	2000	1999
SOIL VS HDWD	2000	2000	2000	2000	2000	2000	2000
SOIL VS SGHD	2000	2000	2000	2000	2000	2000	2000
SOIL VS TUPE	2000	2000	2000	1997	2000	2000	2000
SOIL VS SYCA	2000	2000	2000	2000	2000	2000	2000
SOIL VS CCUT	1795	1903	1834	1855	1924	1588	1525
SOIL VS MVEG	1853	1860	1830	1826	1833	1851	1903
SOIL VS WATR	1824	1888	1870	1924	1970	1980	1861
PAST VS CROP	1585	1662	1603	1633	1670	1716	1591
PAST VS PINE	1973	1911	1964	1933	1544	1972	1840
PAST VS PIHD	1988	1914	1991	1936	1808	1992	1920
PAST VS HDWD	1956	1942	1923	1909	1960	1828	1976
PAST VS SGHD	1920	1966	1875	1919	1982	1672	1849
PAST VS TUPE	1730	1910	1459	1526	1850	1860	1575
PAST VS SYCA	1951	1995	1750	1779	1998	1881	1795
PAST VS CCUT	1712	1663	1692	1545	1469	1732	1757
PAST VS MVEG	1904	1872	1764	1732	1467	1945	1740
PAST VS WATR	1969	1996	1998	2000	1984	1985	1993
CROP VS PINE	1885	1725	1839	1779	1429	1649	1573
CROP VS PIHD	1938	1864	1934	1997	1800	1872	1671
CROP VS HDWD	1994	1989	1927	1940	1956	1729	1815
CROP VS SGHD	1985	1946	1956	1924	1965	1699	1930
CROP VS TUPE	1905	1843	1754	1679	1866	1898	1793
CROP VS SYCA	1952	1974	1746	1811	1998	1963	1864
CROP VS CCUT	1566	1457	1527	1461	1477	1521	1501
CROP VS MVEG	1637	1436	1436	1251	1194	1523	1453
CROP VS WATR	1944	1965	1995	1998	1945	1924	1991
PINE VS PIHD	1265	1251	1165	1170	1485	1418	1249
PINE VS HDWD	1481	1454	1479	1377	1417	1343	1472
PINE VS SGHD	1393	1893	1881	1845	1768	1730	1916
PINE VS TUPE	1955	1895	1832	1815	1665	1930	1833
PINE VS SYCA	1994	1997	1985	1991	1992	1999	1983
PINE VS CCUT	1341	1271	1212	1128	1590	1592	922
PINE VS MVEG	1182	1105	1563	1579	1281	1113	1565
PINE VS WATR	1990	1994	1999	1999	1969	1766	1998
PIHD VS HDWD	1781	1771	1773	1731	1893	1459	1937
PIHD VS SGHD	1995	1994	1991	1985	1999	1891	1997
PIHD VS TUPE	1916	1786	1708	1901	1949	1922	1977
PIHD VS SYCA	2000	2000	1999	1999	2000	2000	1998
PIHD VS CCUT	1641	1646	1635	1646	1995	1892	1687
PIHD VS MVEG	1490	1519	1774	1802	1765	1566	1392
PIHD VS WATR	1999	2000	2000	2000	2000	1938	2000
HDWD VS SGHD	1470	1500	1499	1505	1431	1233	1543
HDWD VS TUPE	1963	1953	1980	1976	1898	1875	1510
HDWD VS SYCA	1989	1992	1983	1988	1968	1996	1979
HDWD VS CCUT	1780	1775	1649	1598	1845	1867	1377
HDWD VS MVEG	1916	1931	1934	1876	1953	1730	1957
HDWD VS WATR	2000	2000	2000	2000	2000	1983	2000
SGHD VS TUPE	1905	1922	1941	1956	1929	1574	1652
SGHD VS SYCA	1967	1965	1924	1917	1948	1919	1958
SGHD VS CCUT	1935	1932	1892	1842	1755	1877	1906
SGHD VS MVEG	1996	1998	1997	1938	1987	1936	1998
SGHD VS WATR	2000	2000	2000	2000	2000	1999	2000
TUPE VS SYCA	1722	1827	1710	1838	1754	1698	1704
TUPE VS CCUT	1816	1750	1856	1777	1641	1854	1770
TUPE VS MVEG	1942	1921	1810	1746	1862	1961	1966
TUPE VS WATR	2000	2000	2000	2000	2000	1999	2000
SYCA VS CCUT	1972	1992	1920	1932	1734	1935	1980
SYCA VS MVEG	1999	2000	1995	1999	1998	1999	1996
SYCA VS WATR	2000	2000	2000	2000	2000	2000	2000
CCUT VS MVEG	1105	1203	1014	1120	1318	1250	1304
CCUT VS WATR	1814	1859	1937	1978	1959	1797	1947
MVEG VS WATR	1841	1956	1949	1982	1896	1751	1963

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-2. Averaged and Minimum Transformed Divergence Values for Each of Best 2-Channel Combinations by Cover Class Pair (cont'd.).

Minimum

Channels

3,4	3,5	2,4	2,5	3,6	4,6	1,4
1764	1860	1719	1357	1760	1183	1465
1667	1141	1619	897	247	1298	1615
2000	2000	2000	2000	2000	1965	1986
2000	2000	2000	2000	2000	2000	1995
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	1999	1985	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1194	1245	1442	1512	1241	423	1362
1444	1540	1501	1496	1169	1282	1524
768	1031	1165	1291	1656	1775	1201
788	474	730	554	639	692	885
1904	1573	1893	1761	672	1857	1430
1939	1342	1950	1506	722	1940	1587
1665	1549	1493	1369	1705	729	1423
1443	1785	1243	1613	1912	601	1368
544	1054	49	122	1424	1207	497
1609	1959	1068	1150	1958	1066	1053
1216	597	1213	717	706	1188	1379
1669	1579	983	1454	243	1733	787
1512	1934	1970	2000	1747	1764	1886
1557	750	1404	1214	122	554	578
1642	1070	1666	1343	941	1069	619
1959	1947	1478	1665	1720	306	910
1911	1575	1811	1447	1003	706	1569
1518	924	1005	653	1159	1425	883
1793	1793	1112	535	1969	1646	1381
735	727	572	714	605	767	485
495	488	345	364	354	253	263
1227	1545	1945	1981	1340	1162	1923
549	364	643	286	1006	691	477
844	891	742	761	647	736	1002
1758	1782	1724	1702	1407	1230	1788
1831	1794	1449	1466	953	1747	1404
1974	1985	1942	1972	1981	1998	1930
665	764	525	655	1220	1252	205
292	79	1226	1407	457	539	1105
1946	1957	1994	1994	1793	601	1984
1620	1565	1470	1325	1622	1273	1821
1983	1984	1972	1955	1996	1603	1989
1853	1353	857	1694	1569	1734	1913
1998	1999	1997	1997	2000	2000	1992
724	703	746	766	1983	1581	1476
221	517	1262	1455	1200	371	420
1996	2000	1999	2000	1996	1562	1997
1028	1116	1018	1047	833	230	1108
1859	1819	1925	1907	1726	1508	905
1956	1968	1931	1951	1975	1985	1914
1233	1186	823	670	1390	1483	389
1761	1808	1800	1763	1874	1347	1936
1999	1999	2000	2000	1996	1921	2000
1622	1691	1764	1823	1718	634	656
1867	1861	1694	1669	1867	1683	1830
1761	1760	1647	1493	1069	1678	1450
1965	1994	1989	1981	1947	1821	1994
2000	2000	2000	2000	2000	1997	2000
889	1307	943	1352	1491	794	818
1273	1005	1553	1410	567	1415	1182
1783	1703	1516	1621	1455	1845	1368
2000	2000	2000	2000	2000	1989	2000
1867	1928	1661	1732	1457	1738	1922
1994	1999	1979	1997	1994	1997	1985
2000	2000	2000	2000	2000	2000	2000
433	712	587	711	404	774	785
887	1054	1624	1869	1747	989	1724
816	1719	1689	1924	1454	777	1795

Table C-3. Averaged and Minimum Transformed Divergence Values for Each of Best 3-Channel Combinations by Cover Class Pair.

Averaged

Channels

	A	B	C	D	E	F	G
SOIL VS PAST	1991	1985	1990	1991	1987	1994	1969
SOIL VS CROP	1964	1968	1965	1979	1962	1977	1946
SOIL VS PINE	2000	2000	2000	2000	2000	2000	2000
SOIL VS PIHD	2000	2000	2000	2000	2000	2000	2000
SOIL VS HDWD	2000	2000	2000	2000	2000	2000	2000
SOIL VS SGHD	2000	2000	2000	2000	2000	2000	2000
SOIL VS TUPE	2000	2000	2000	2000	2000	2000	2000
SOIL VS SYCA	2000	2000	2000	2000	2000	2000	2000
SOIL VS CCUT	1910	1893	1834	1939	1931	1932	1862
SOIL VS MVEG	1906	1903	1942	1874	1917	1953	1970
SOIL VS WATR	1930	1993	1992	1982	1996	1995	1992
PAST VS CROP	1943	1995	1699	1925	1873	1677	1723
PAST VS PINE	1994	1996	1983	1989	1993	1952	1964
PAST VS PIHD	1999	2000	1990	1999	1999	1992	1995
PAST VS HDWD	1995	1995	1990	1975	1966	1954	1968
PAST VS SGHD	1987	1987	1987	1946	1945	1945	1942
PAST VS TUPE	1952	1920	1903	1955	1999	1877	1811
PAST VS SYCA	2000	2000	2000	1998	1919	1936	1962
PAST VS CCUT	1553	1839	1865	1842	1826	1949	1825
PAST VS MVEG	1950	1959	1932	1951	1965	1929	1966
PAST VS WATR	2000	2000	2000	2000	2000	2000	1996
CROP VS PINE	1994	1979	1941	1944	1926	1921	1945
CROP VS PIHD	2000	1998	1999	1994	1992	1994	1999
CROP VS HDWD	2000	2000	2000	1982	1969	1972	1995
CROP VS SGHD	2000	1999	1998	1994	1987	1995	1990
CROP VS TUPE	1991	1988	1979	1958	1909	1864	1938
CROP VS SYCA	2000	1999	2000	1999	1973	1965	1988
CROP VS CCUT	1917	1874	1856	1886	1836	1833	1657
CROP VS MVEG	1889	1713	1701	1822	1661	1675	1967
CROP VS WATR	1993	1998	1997	2000	2000	2000	1999
PINE VS PIHD	1636	1835	1890	1648	1819	1820	1759
PINE VS HDWD	1591	1559	1527	1619	1549	1499	1553
PINE VS SGHD	1925	1927	1908	1917	1912	1890	1946
PINE VS TUPE	1983	1972	1951	1991	1967	1981	1976
PINE VS SYCA	1998	2000	2000	1997	2000	2000	1996
PINE VS CCUT	1643	1757	1754	1546	1696	1620	1596
PINE VS MVEG	1840	1707	1507	1905	1892	1874	1770
PINE VS WATR	1999	1997	1999	2000	2000	2000	1999
PIHD VS HDWD	1852	1936	1946	1954	1920	1889	1971
PIHD VS SGHD	1997	2000	2000	1995	2000	1999	1999
PIHD VS TUPE	1997	1987	1986	2000	1979	1980	1996
PIHD VS SYCA	2000	2000	2000	2000	2000	2000	2000
PIHD VS CCUT	1753	2000	2000	1741	1994	1995	1990
PIHD VS MVEG	1993	1955	1935	1997	1996	1996	1640
PIHD VS WATR	2000	2000	2000	2000	2000	2000	2000
HDWD VS SGHD	1620	1662	1653	1611	1639	1628	1712
HDWD VS TUPE	1977	1971	1962	1987	1966	1983	1970
HDWD VS SYCA	1994	1998	1998	1993	1996	1998	1994
HDWD VS CCUT	1818	1891	1895	1780	1865	1890	1827
HDWD VS MVEG	1984	1959	1964	1986	1975	1968	1964
HDWD VS WATR	2000	2000	2000	2000	2000	2000	2000
SGHD VS TUPE	1957	1939	1938	1973	1965	1965	1909
SGHD VS SYCA	1970	1977	1978	1941	1965	1968	1984
SGHD VS CCUT	1946	1940	1959	1920	1927	1954	1940
SGHD VS MVEG	1999	1999	1999	1999	1996	1998	1999
SGHD VS WATR	2000	2000	2000	2000	2000	2000	2000
TUPE VS SYCA	1962	1900	1907	1958	1863	1901	1950
TUPE VS CCUT	1949	1933	1909	1976	1979	1974	1838
TUPE VS MVEG	1990	1972	1959	1990	1970	1960	1967
TUPE VS WATR	2000	2000	2000	2000	2000	2000	2000
SYCA VS CCUT	1985	1976	1985	1942	1944	1961	2000
SYCA VS MVEG	2000	2000	2000	2000	2000	2000	1999
SYCA VS WATR	2000	2000	2000	2000	2000	2000	2000
CCUT VS MVEG	1665	1565	1636	1678	1620	1677	1944
CCUT VS WATR	1979	1992	1992	1994	1999	1999	1997
MVEG VS WATR	1996	1981	1980	1997	1995	1993	1996

A = 3,4,5

B = 3,4,5

C = 3,5,6

D = 2,4,5

E = 2,4,6

F = 2,5,6

G = 1,3,4

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-3. Averaged and Minimum Transformed Divergence Values for Each of Best 3-Channel Combinations by Cover Class Pair (cont'd.).

Minimum

Channels

A	B	C	D	E	F	G
1937	1596	1932	1912	1807	1936	1778
1826	1620	1796	1922	1926	1904	1685
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1599	1549	1513	1780	1736	1789	1496
1708	1530	1724	1570	1611	1791	1832
1763	1515	1907	1799	1952	1941	1913
1678	1371	1438	1418	1373	1327	988
1978	1964	1903	1946	1971	1697	1928
1995	1998	1923	1997	1994	1937	1963
1966	1961	1924	1838	1773	1667	1752
1926	1931	1922	1735	1726	1708	1599
1733	1579	1561	1753	1305	1250	1128
1998	1999	1949	1324	1305	1493	1695
1446	1317	1453	1462	1372	1491	1443
1707	1731	1654	1719	1604	1667	1855
1995	1993	1998	2000	2000	2000	1940
1961	1900	1699	1694	1606	1541	1341
1999	1981	1996	1952	1950	1472	1991
1999	1999	1997	1837	1772	1309	1962
1999	1944	1996	1970	1944	1917	1347
1931	1933	1561	1671	1503	1433	1677
2000	1994	1998	1995	1672	1685	1937
1476	1194	1091	1484	1239	1200	989
1447	797	775	1306	801	949	1905
1906	1986	1974	1993	1999	1997	1983
1335	1503	1737	1359	1451	1499	1191
945	1038	1063	899	793	773	1101
1805	1827	1809	1762	1702	1734	1930
1931	1896	1871	1966	1955	1944	1927
1991	1999	1999	1987	1999	1999	1984
977	1554	1375	965	1300	947	1243
1451	1304	919	1710	1694	1637	1143
1997	1983	1993	1999	2000	2000	1992
1665	1850	1849	1594	1635	1769	1908
1959	1999	1999	1930	1998	1995	1997
1992	1969	1944	1999	1919	1926	1990
1999	2000	2000	1998	2000	2000	1999
1024	1999	2000	1017	1977	1980	1962
1975	1842	1303	1993	1998	1987	633
2000	2000	2000	2000	2000	2000	2000
1161	1190	1169	1118	1119	1086	1144
1907	1864	1849	1949	1944	1934	1975
1975	1990	1991	1970	1992	1993	1977
1311	1575	1592	1158	1549	1571	1329
1956	1922	1913	1949	1909	1691	1959
2000	2000	2000	2000	2000	2000	2000
1830	1754	1752	1642	1659	1662	1636
1980	1906	1912	1765	1600	1673	1936
1796	1775	1351	1695	1721	1830	1767
1947	1995	1996	1996	1994	1994	1997
2000	2000	2000	2000	2000	2000	2000
1849	1601	1627	1831	1535	1604	1800
1794	1733	1633	1903	1916	1996	1355
1969	1887	1837	1958	1679	1846	1949
2000	2000	2000	2000	2000	2000	2000
1941	1912	1939	1768	1776	1842	2000
2000	2000	2000	1999	2000	2000	1997
2000	2000	2000	2000	2000	2000	2000
1232	591	1315	1226	929	1321	1893
1913	1953	1949	1954	1959	1969	1985
1976	1871	1863	1977	1960	1974	1986

A = 3,4,5

B = 3,4,5

C = 3,5,6

D = 2,4,5

E = 2,4,6

F = 2,5,6

G = 1,3,4

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-4. Averaged and Minimum Transformed Divergence Values for Each of Best 4-Channel Combinations by Cover Class Pair.

Averaged

Channels

			A	B	C	D	E	F	G
SOIL	VS	PAST	1994	1995	1989	1996	1996	1992	1992
SOIL	VS	CROP	1986	1979	1991	1980	1988	1989	1969
SOIL	VS	PINE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	HDWD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	CCUT	1951	1927	1941	1956	1968	1944	1935
SOIL	VS	MVEG	1978	1998	1989	1964	1964	1990	1993
SOIL	VS	WATR	1997	1994	1998	1987	1990	1996	1997
PAST	VS	CROP	1979	1973	1939	1977	1969	1948	1949
PAST	VS	PINE	1998	1998	1998	1999	1997	1997	1990
PAST	VS	PIHD	2000	2000	2000	2000	2000	2000	1992
PAST	VS	HDWD	1996	1997	1996	1999	1993	1996	1992
PAST	VS	SGHD	1993	1990	1994	1998	1991	1995	1993
PAST	VS	TUPE	1978	1976	1953	1996	1994	1999	1934
PAST	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PAST	VS	CCUT	1893	1905	1858	1901	1893	1866	1906
PAST	VS	MVEG	1984	1977	1989	1983	1983	1989	1976
PAST	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CROP	VS	PINE	2000	1994	1995	1999	1993	1985	1961
CROP	VS	PIHD	2000	2000	2000	2000	1999	1999	2000
CROP	VS	HDWD	2000	2000	2000	2000	1996	2000	2000
CROP	VS	SGHD	2000	2000	2000	2000	1999	2000	1999
CROP	VS	TUPE	1998	1998	1997	1998	1993	2000	1988
CROP	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
CROP	VS	CCUT	1939	1937	1919	1954	1937	1909	1908
CROP	VS	MVEG	2000	1959	1996	1970	1976	1943	1993
CROP	VS	WATR	2000	1999	2000	2000	2000	2000	2000
PINE	VS	PIHD	1891	1964	1884	1834	1837	1580	1927
PINE	VS	HDWD	1705	1689	1688	1627	1653	1716	1670
PINE	VS	SGHD	1951	1957	1954	1951	1941	1965	1946
PINE	VS	TUPE	1995	1989	1985	1989	1994	1996	1966
PINE	VS	SYCA	1999	2000	2000	1998	1997	2000	2000
PINE	VS	CCUT	1817	1930	1825	1860	1805	1819	1792
PINE	VS	MVEG	1942	1395	1933	1865	1927	1944	1902
PINE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	HDWD	1965	1988	1988	1941	1945	1963	1969
PIHD	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	TUPE	2000	2000	1998	1999	2000	2000	1994
PIHD	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	CCUT	1995	2000	2000	1957	1932	2000	2000
PIHD	VS	MVEG	1995	1999	1972	1996	1999	2000	1971
PIHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
HDWD	VS	SGHD	1743	1634	1753	1702	1696	1703	1747
HDWD	VS	TUPE	1981	1975	1975	1984	1993	1987	1966
HDWD	VS	SYCA	1998	1999	1999	1996	1956	1999	1999
HDWD	VS	CCUT	1845	1909	1903	1905	1899	1944	1906
HDWD	VS	MVEG	1999	1987	1998	1987	1988	1990	1997
HDWD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SGHD	VS	TUPE	1973	1959	1956	1963	1976	1973	1950
SGHD	VS	SYCA	1987	1991	1990	1985	1964	1992	1990
SGHD	VS	CCUT	1957	1969	1949	1966	1950	1981	1966
SGHD	VS	MVEG	2000	1993	2000	2000	1999	2000	2000
SGHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
TUPE	VS	SYCA	1999	1970	1994	1975	1975	1910	1993
TUPE	VS	CCUT	1966	1962	1956	1958	1961	1993	1927
TUPE	VS	MVEG	2000	1992	1998	1995	1995	1986	1990
TUPE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	CCUT	2000	1993	2000	1996	1987	1999	2000
SYCA	VS	MVEG	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CCUT	VS	MVEG	1993	1994	1987	1919	1943	1826	1984
CCUT	VS	WATR	2000	1994	2000	1999	2000	2000	2000
MVEG	VS	WATR	2000	1995	2000	1998	1999	1999	1999

A = 1,3,4,5

B = 3,4,5,6

C = 1,3,4,6

D = 3,4,5,7

E = 2,4,5,7

F = 2,3,4,6

G = 1,3,5,6

Table C-4. Averaged and Minimum Transformed Divergence Values for Each of Best 4-Channel Combinations by Cover Class Pair (cont'd.).

Minimum

Channels

A	B	C	D	E	F	G
1946	1963	1966	1961	1955	1917	1938
1946	1873	1964	1913	1936	1951	1959
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1791	1634	1769	1817	1961	1831	1750
1872	1936	1942	1793	1793	1949	1963
1960	1925	1970	1849	1679	1957	1961
1877	1797	1530	1855	1738	1719	1628
1988	1992	1992	1994	1968	1986	1931
2000	2000	1999	2000	2000	1999	1935
1971	1978	1968	1988	1946	1970	1937
1961	1948	1967	1984	1944	1964	1957
1867	1890	1741	1980	1959	1996	1696
1999	1999	2000	2000	1998	2000	2000
1579	1579	1516	1574	1664	1414	1605
1837	1865	1932	1899	1699	1933	1867
2000	1993	2000	2000	2000	2000	2000
1998	1985	1967	1989	1956	1921	1919
2000	2000	2000	2000	1995	1993	2000
2000	2000	2000	2000	1971	2000	1999
2000	1999	1999	1999	1994	1998	1994
1986	1984	1977	1987	1946	2000	1906
2000	2000	1999	2000	2000	2000	1999
1599	1563	1431	1704	1711	1377	1361
1997	1729	1975	1779	1829	1694	1967
1999	1991	2000	1993	2000	1999	2000
1655	1937	1586	1590	1628	1621	1786
1166	1238	1189	1008	974	1259	1181
1837	1864	1855	1948	1613	1887	1835
1978	1954	1940	1954	1977	1983	1902
1995	2000	2000	1992	1988	2000	2000
1592	1777	1577	1609	1606	1635	1410
1768	1615	1731	1466	1721	1799	1613
1998	1999	1995	1999	2000	2000	1998
1950	1965	1964	1867	1670	1893	1971
1998	2000	2000	1999	1998	2000	2000
2000	2000	1992	1997	1999	2000	1976
2000	2000	2000	1999	1999	2000	2000
1979	2000	2000	1828	1731	1999	2000
1979	1997	1891	1963	1997	1999	1888
2000	2000	2000	2000	2000	2000	2000
1224	1213	1231	1205	1162	1213	1209
1925	1910	1898	1935	1970	1949	1862
1990	1996	1996	1985	1964	1997	1996
1392	1644	1616	1626	1601	1780	1625
1996	1964	1992	1963	1956	1965	1987
2000	2000	2000	2000	2000	2000	2000
1892	1836	1824	1851	1905	1890	1798
1948	1924	1956	1940	1655	1966	1960
1834	1886	1801	1873	1810	1926	1868
2000	1997	1999	1998	1997	1998	1999
2000	2000	2000	2000	2000	2000	2000
1996	1880	1975	1899	1901	1639	1971
1871	1846	1824	1831	1924	1973	1709
1999	1969	1991	1980	1978	1944	1961
2000	2000	2000	2000	2000	2000	2000
2000	1973	2000	1985	1946	1997	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1981	1761	1969	1818	1668	1549	1969
1996	1958	1998	1994	2000	1999	1997
1996	1935	1996	1992	1992	1986	1991

A = 1,3,4,5

B = 3,4,5,6

C = 1,3,4,6

D = 3,4,5,7

E = 2,4,5,7

F = 2,3,4,6

G = 1,3,5,6

Table C-5. Averaged and Minimum Transformed Divergence Values for Each of Best 5-Channel Combinations by Cover Class Pair.

Averaged

Channels

			A	B	C	D	E	F	G
SOIL	VS	PAST	1998	1999	1997	1998	1999	1999	1995
SOIL	VS	CROP	1994	1994	1990	1994	1990	1995	1992
SOIL	VS	PINE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	HDWD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	CCUT	1962	1967	1969	1977	1969	1982	1964
SOIL	VS	MVEG	2000	2000	1995	1999	2000	2000	1997
SOIL	VS	WATR	1996	1997	1998	1998	1996	1998	1998
PAST	VS	CROP	1992	1985	1988	1991	1990	1982	1973
PAST	VS	PINE	1999	1999	1999	1999	2000	1999	1995
PAST	VS	PIHD	2000	2000	2000	2000	2000	2000	1999
PAST	VS	HDWD	1998	1998	1998	1999	1999	1994	1994
PAST	VS	SGHD	1996	1997	1997	1999	1999	1995	1996
PAST	VS	TUPE	1993	2000	2000	1999	1999	1996	1999
PAST	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PAST	VS	CCUT	1932	1925	1925	1931	1936	1926	1938
PAST	VS	MVEG	1994	1993	1991	1995	1990	1992	1992
PAST	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CROP	VS	PINE	2000	1999	2000	2000	2000	1999	1993
CROP	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
CROP	VS	HDWD	2000	2000	2000	2000	2000	1999	2000
CROP	VS	SGHD	2000	2000	2000	2000	2000	1999	2000
CROP	VS	TUPE	2000	2000	2000	1999	2000	1997	2000
CROP	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
CROP	VS	CCUT	1958	1953	1943	1969	1951	1965	1920
CROP	VS	MVEG	2000	1995	2000	2000	1990	1991	1996
CROP	VS	WATR	2000	2000	2000	2000	2000	2000	2000
PINE	VS	PIHD	1989	1985	1908	1928	1975	1965	1944
PINE	VS	HDWD	1772	1779	1785	1717	1730	1714	1778
PINE	VS	SGHD	1967	1973	1972	1958	1970	1956	1970
PINE	VS	TUPE	1996	1997	2000	1996	1991	1995	2000
PINE	VS	SYCA	2000	2000	2000	1999	2000	2000	2000
PINE	VS	CCUT	1956	1933	1956	1906	1959	1948	1952
PINE	VS	MVEG	1965	1963	1920	1950	1913	1950	1971
PINE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	HDWD	1999	1994	1995	1994	1995	1996	1996
PIHD	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	CCUT	2000	2000	1999	1999	2000	2000	2000
PIHD	VS	MVEG	2000	2000	2000	1997	2000	2000	2000
PIHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
HDWD	VS	SGHD	1765	1718	1766	1759	1728	1712	1772
HDWD	VS	TUPE	1982	1989	1991	1987	1984	1993	1967
HDWD	VS	SYCA	2000	2000	1999	1998	2000	2000	2000
HDWD	VS	CCUT	1921	1955	1925	1918	1938	1940	1961
HDWD	VS	MVEG	1999	1995	2000	1999	1989	1989	1998
HDWD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SGHD	VS	TUPE	1976	1979	1993	1981	1955	1977	1990
SGHD	VS	SYCA	1992	1994	1996	1992	1994	1991	1997
SGHD	VS	CCUT	1975	1993	1988	1972	1977	1973	1992
SGHD	VS	MVEG	2000	2000	2000	2000	2000	1999	2000
SGHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
TUPE	VS	SYCA	1999	1974	1999	1999	1981	1962	1995
TUPE	VS	CCUT	1984	1995	1997	1976	1971	1990	1996
TUPE	VS	MVEG	2000	1996	2000	2000	1996	1995	1999
TUPE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	CCUT	2000	2000	2000	2000	1998	1995	2000
SYCA	VS	MVEG	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CCUT	VS	MVEG	1998	1979	1997	1999	1962	1979	1990
CCUT	VS	WATR	2000	2000	2000	2000	2000	2000	2000
MVEG	VS	WATR	2000	1999	2000	2000	1999	1999	1999

A = 1,3,4,5,6

B = 2,3,4,5,6

C = 1,2,3,4,5

D = 1,3,4,5,7

E = 3,4,5,6,7

F = 2,4,5,6,7

G = 1,2,3,5,6

Table C-5. Averaged and Minimum Transformed Divergence Values for Each of Best 5-Channel Combinations by Cover Class Pair (cont'd.).

Minimum

Channels

A	B	C	D	E	F	G
1983	1990	1961	1977	1990	1991	19
1977	1973	1956	1963	1960	1970	19
2000	2000	2000	2000	2000	2000	20
2000	2000	2000	2000	2000	2000	200
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1816	1363	1879	1913	1658	1938	1874
2000	2000	1968	1996	1997	1997	1984
1974	1963	1975	1971	1952	1974	1975
1933	1930	1924	1946	1939	1828	1832
1998	1995	1991	1996	1959	1996	1963
2000	2000	2000	2000	2000	2000	1993
1982	1985	1962	1992	1994	1955	1950
1979	1978	1977	1991	1995	1969	1969
1956	1999	1999	1991	1997	1972	1995
2000	2000	2000	2000	2000	1999	2000
1681	1642	1715	1669	1637	1661	1768
1961	1954	1932	1968	1939	1949	1957
2000	2000	2000	2000	2000	2000	2000
1999	1995	1999	1999	1999	1993	1959
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	1990	1999
2000	2000	2000	2000	2000	1997	1997
2000	2000	2000	1995	2000	1976	1999
2000	2000	2000	2000	2000	2000	2000
1685	1642	1609	1765	1607	1824	1434
2000	1959	1999	2000	1967	1938	1977
2000	2000	2000	2000	1999	2000	2000
1974	1980	1707	1770	1947	1961	1826
1362	1390	1407	1196	1307	1148	1430
1883	1905	1908	1859	1699	1854	1900
1982	1989	1999	1983	1904	1980	1999
2000	2000	2000	1996	2000	2000	2000
1873	1797	1639	1775	1658	1841	1575
1863	1854	1921	1798	1654	1806	1885
1999	2000	2000	2000	2000	2000	2000
1999	1975	1949	1981	1908	1988	1990
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	1994	1995	2000	2000	2000
1998	2000	2000	1987	1999	1999	2000
2000	2000	2000	2000	2000	2000	2000
1258	1243	1277	1243	1237	1178	1269
1926	1955	1965	1948	1937	1971	1949
1998	1999	1997	1993	1999	1999	1999
1684	1826	1765	1673	1754	1762	1845
1996	1983	1998	1997	1909	1957	1992
2000	2000	2000	2000	2000	2000	2000
1903	1915	1970	1925	1601	1908	1960
1966	1975	1963	1969	1974	1965	1987
1902	1972	1952	1892	1912	1896	1970
2000	1999	2000	2000	19[illegible]8	1997	2000
2000	2000	2000	2000	2000	2000	2000
1997	1897	1997	1996	1924	1928	1981
1934	1979	1956	1902	1603	1961	1983
1999	1983	2000	1999	1964	1981	1995
2000	2000	2000	2000	2000	2000	2000
2000	1999	2000	2000	1992	1981	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1994	1949	1991	1996	1692	1959	1996
1998	1999	1959	2000	1979	2000	1999
1997	1993	1998	1998	1994	1995	1993

A = 1,3,4,5,6

B = 2,3,4,5,6

C = 1,2,3,4,5

D = 1,3,4,5,7

E = 3,4,5,6,7

F = 2,4,5,6,7

G = 1,2,3,5,6

Table C-6. Averaged and Minimum Transformed Divergence Values for Each of Best 6-Channel Combinations by Cover Class Pair.

Averaged

Channels

			A	B	C	D	E	F	G
SOIL	VS	PAST	1999	1999	1999	1998	1999	1999	1997
SOIL	VS	CROP	1995	1997	1997	1996	1997	1995	1996
SOIL	VS	PINE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	HDWD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
SOIL	VS	CCUT	1977	1985	1983	1983	1968	1986	1963
SOIL	VS	MVEG	2000	2000	2000	1999	2000	2000	1999
SOIL	VS	WATR	1999	1997	1999	1999	1999	1999	1999
PAST	VS	CROP	1994	1995	1996	1991	1991	1994	1956
PAST	VS	PINE	2000	2000	2000	1995	2000	2000	2000
PAST	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
PAST	VS	HDWD	1998	2000	2000	1998	1997	1999	1999
PAST	VS	SGHD	1995	2000	2000	2000	1998	2000	2000
PAST	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
PAST	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PAST	VS	CCUT	1952	1954	1956	1966	1948	1950	1954
PAST	VS	MVEG	1998	1997	1998	1996	1996	1998	1996
PAST	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CROP	VS	PINE	2000	2000	2000	1999	2000	2000	2000
CROP	VS	PIHD	2000	2000	2000	2000	2000	2000	2000
CROP	VS	HDWD	2000	2000	2000	2000	1999	2000	2000
CROP	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
CROP	VS	TUPE	2000	2000	2000	2000	1999	2000	2000
CROP	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
CROP	VS	CCUT	1950	1986	1985	1977	1979	1971	1975
CROP	VS	MVEG	2000	1999	2000	1998	2000	2000	1999
CROP	VS	WATR	2000	2000	2000	2000	2000	2000	2000
PINE	VS	PIHD	1993	1999	1992	1955	1994	1939	1920
PINE	VS	HDWD	1828	1807	1792	1816	1795	1799	1816
PINE	VS	SGHD	1979	1980	1974	1978	1970	1977	1960
PINE	VS	TUPE	2000	1998	1997	2000	2000	2000	2000
PINE	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PINE	VS	CCUT	1966	1967	1973	1924	1968	1930	1933
PINE	VS	MVEG	1988	1970	1971	1975	1975	1983	1963
PINE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	HDWD	2000	1997	2000	1999	2000	1998	1999
PIHD	VS	SGHD	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	TUPE	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	CCUT	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	MVEG	2000	2000	2000	2000	2000	2000	2000
PIHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
HDWD	VS	SGHD	1784	1755	1774	1780	1761	1780	1764
HDWD	VS	TUPE	1992	1994	1987	1994	1995	1995	1995
HDWD	VS	SYCA	2000	2000	2000	2000	2000	2000	2000
HDWD	VS	CCUT	1966	1972	1947	1977	1963	1966	1973
HDWD	VS	MVEG	2000	1996	1999	1999	1999	2000	1999
HDWD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SGHD	VS	TUPE	1994	1992	1993	1995	1996	1996	1995
SGHD	VS	SYCA	1997	1999	1997	2000	1997	1999	2000
SGHD	VS	CCUT	1995	1994	1981	1995	1986	1993	1990
SGHD	VS	MVEG	2000	2000	2000	2000	2000	2000	2000
SGHD	VS	WATR	2000	2000	2000	2000	2000	2000	2000
TUPE	VS	SYCA	2000	1986	2000	1997	1999	1999	1997
TUPE	VS	CCUT	1995	1997	1986	1997	1997	1993	1995
TUPE	VS	MVEG	2000	1998	2000	2000	2000	2000	2000
TUPE	VS	WATR	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	CCUT	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	MVEG	2000	2000	2000	2000	2000	2000	2000
SYCA	VS	WATR	2000	2000	2000	2000	2000	2000	2000
CCUT	VS	MVEG	1999	1999	1999	1996	1997	1999	1995
CCUT	VS	WATR	2000	2000	2000	2000	2000	2000	2000
MVEG	VS	WATR	2000	2000	2000	2000	2000	2000	2000

A = 1,2,3,4,5,6

B = 2,3,4,5,6,7

C = 1,3,4,5,6,7

D = 1,2,3,5,6,7

E = 1,2,4,5,6,7

F = 1,2,3,4,5,7

G = 1,2,3,4,6,7

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-6 . Averaged and Minimum Transformed Divergence Values for Each of Best 6-Channel Combinations by Cover Class Pair (cont'd.).

Minimum

Channels

A	B	C	D	E	F	G
1993	1993	1994	1976	[illegible]	1984	1964
1990	1977	1982	1972	1979	1964	[illegible]
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1894	1956	1931	1935	1950	1954	1935
2000	2000	2000	1995	1999	1999	1991
1984	1977	1965	1985	1964	1982	1989
1947	1970	1967	1943	1934	1956	1878
1998	1999	1999	1988	1998	1997	1999
2000	2000	2000	1999	2000	2000	2000
1968	1997	1996	1965	1977	1995	1993
1986	1998	1997	1997	1985	1996	1998
2000	2000	1999	2000	2000	2000	2000
2000	2000	2000	2000	1999	2000	2000
1790	1720	1735	1799	1735	1766	1727
1983	1980	1983	1979	1969	1983	1987
2000	2000	2000	2000	2000	2000	2000
1999	1999	2000	1992	1999	2000	1999
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	1999	1994	2000	2000
2000	2000	2000	1996	1999	2000	2000
2000	2000	2000	2000	1993	2000	2000
2000	2000	2000	2000	2000	2000	2000
1693	1900	1913	1832	1662	1789	1820
2000	1994	2000	1987	1999	2000	1996
2000	2000	2000	2000	2000	2000	2000
1965	1983	1979	1855	1967	1799	1710
1535	1471	1416	1536	1441	1451	1537
1925	1928	1905	1925	1897	1924	1932
2000	1993	1965	1999	1999	1999	1999
2000	2000	2000	2000	2000	2000	2000
1899	1881	1912	1783	1914	1836	1834
1950	1981	1984	1900	1901	1931	1933
2000	2000	2000	2000	2000	2000	2000
1998	1990	1999	1997	1999	1996	1997
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	1999	2000
2000	2000	1999	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1306	1264	1255	1277	1250	1290	1289
1966	1974	1949	1976	1979	1981	1979
1999	2000	1999	2000	2000	1999	2000
1866	1889	1790	1908	1653	1865	1893
1998	1986	1997	1994	1994	1998	1997
2000	2000	2000	2000	2000	2000	2000
1975	1927	1931	1980	1963	1985	1981
1989	1996	1987	1998	1969	1995	1998
1979	1977	1926	1979	1946	1974	1961
2000	1999	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1998	1944	1998	1968	1995	1997	1986
1993	1987	[illegible]	1988	1969	1991	1991
2000	1992	1999	1996	2000	2000	1999
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	1995	2000	2000
2000	2000	2000	2000	2000	2000	2000
2000	2000	2000	2000	2000	2000	2000
1997	1971	1993	1992	1992	1998	1991
2000	2000	2000	2000	2000	2000	2000
1999	1999	1999	1999	1997	2000	2000

A = 1,2,3,4,5,6

B = 2,3,4,5,6,7

C = 1,3,4,5,6,7

D = 1,2,3,5,6,7

E = 1,2,4,5,6,7

F = 1,2,3,4,5,7

G = 1,2,3,4,6,7

Table C-7. Averaged and Minimum Transformed Divergence Values for the 7-Channel Combination by Cover Class Pair.

			Ave.	Min.
SOIL	VS	PAST	2000	1996
SOIL	VS	CROP	1998	1945
SOIL	VS	PINE	2000	2000
SOIL	VS	PIHD	2000	2000
SOIL	VS	HDWD	2000	2000
SOIL	VS	SGHD	2000	2000
SOIL	VS	TUPE	2000	2000
SOIL	VS	SYCA	2000	2000
SOIL	VS	CCUT	1991	1965
SOIL	VS	MVEG	2000	2000
SOIL	VS	WATR	1999	1991
PAST	VS	CROP	1997	1973
PAST	VS	PINE	2000	2000
PAST	VS	PIHD	2000	2000
PAST	VS	HDWD	2000	1998
PAST	VS	SGHD	2000	1999
PAST	VS	TUPE	2000	2000
PAST	VS	SYCA	2000	2000
PAST	VS	CCUT	1970	1813
PAST	VS	MVEG	1999	1992
PAST	VS	WATR	2000	2000
CROP	VS	PINE	2000	2000
CROP	VS	PIHD	2000	2000
CROP	VS	HDWD	2000	2000
CROP	VS	SGHD	2000	2000
CROP	VS	TUPE	2000	2000
CROP	VS	SYCA	2000	2000
CROP	VS	CCUT	1989	1915
CROP	VS	MVEG	2000	2000
CROP	VS	WATR	2000	2000
PINE	VS	PIHD	1995	1988
PINE	VS	HDWD	1851	1604
PINE	VS	SGHD	1984	1942
PINE	VS	TUPE	2000	2000
PINE	VS	SYCA	2000	2000
PINE	VS	CCUT	1980	1933
PINE	VS	MVEG	1989	1956
PINE	VS	WATR	2000	2000
PIHD	VS	HDWD	2000	1999
PIHD	VS	SGHD	2000	2000
PIHD	VS	TUPE	2000	2000
PIHD	VS	SYCA	2000	2000
PIHD	VS	CCUT	2000	2000
PIHD	VS	MVEG	2000	2000
PIHD	VS	WATR	2000	2000
HDWD	VS	SGHD	1793	1314
HDWD	VS	TUPE	1996	1962
HDWD	VS	SYCA	2000	2000
HDWD	VS	CCUT	1961	1923
HDWD	VS	MVEG	2000	1999
HDWD	VS	WATR	2000	2000
SGHD	VS	TUPE	1997	1986
SGHD	VS	SYCA	2000	1998
SGHD	VS	CCUT	1997	1936
SGHD	VS	MVEG	2000	2000
SGHD	VS	WATR	2000	2000
TUPE	VS	SYCA	2000	1998
TUPE	VS	CCUT	1999	1995
TUPE	VS	MVEG	2000	2000
TUPE	VS	WATR	2000	2000
SYCA	VS	CCUT	2000	2000
SYCA	VS	MVEG	2000	2000
SYCA	VS	WATR	2000	2000
CCUT	VS	MVEG	2000	1999
CCUT	VS	WATR	2000	2000
MVEG	VS	WATR	2000	2000

Table C-8. Average Transformed Divergence Values for Each Channel by Cover Class.

Channels

	6	3	1	5	2	4	7
SOIL	1808	1820	1730	1249	1771	1195	1558
PAST	1476	1401	1318	1474	1338	1397	1373
CROP	1322	1390	1249	1267	1231	1313	1067
PINE	1236	1272	1316	1177	1435	1178	1074
PIHD	1555	1327	1344	1574	1580	1416	831
HDWD	1490	1688	1564	1270	1640	1236	1179
SGHD	1263	1691	1572	1322	1601	1484	906
TUPE	1658	1569	1407	1532	1308	1536	955
SYCA	1752	1713	1618	1753	1297	1752	981
CCUT	1329	1231	1195	1165	1119	1179	1257
MVEG	1251	1261	1195	1292	1073	1270	1041
WATR	1722	1433	1608	1853	1495	1791	1012

Table C-9. Average Transformed Divergence Values for Each of the Best Seven 2-Channel Combination by Cover Class.

Channels

	3.4	3,5	2,4	2,5	3,6	4,6	1,4
SOIL	1932	1934	1941	1937	1915	1922	1926
PAST	1865	1875	1820	1928	1803	1857	1809
CROP	1936	1796	1792	1757	1734	1775	1747
PINE	1780	1733	1774	1747	1661	1716	1708
PIHD	1858	1829	1855	1855	1883	1845	1822
HDWD	1831	1879	1802	1845	1861	1754	1811
SGHD	1929	1933	1917	1912	1914	1765	1895
TUPE	1896	1837	1811	1821	1574	1584	1803
SYCA	1962	1979	1897	1920	1959	1947	1925
CCUT	1667	1671	1672	1655	1654	1707	1655
MVEG	1736	1724	1733	1716	1657	1709	1739
WATR	1941	1965	1976	1983	1973	1927	1975

ORIGINAL PAGE IS
OF POOR QUALITY

Table C-10. Averaged Transformed Divergence Values for Each of the Best Seven 3-Channel Combinations by Cover Class.

Channels

	A	B	C	D	E	F	G
SOIL	1977	1978	[illegible]	[illegible]	[illegible]	1957	1975
PAST	1971	1960	1958	1955	1944	1941	1915
CROP	1971	1947	1941	1955	1925	1922	1914
PINE	1903	1912	1888	1895	1910	1896	1900
PIHD	1947	1980	1962	1946	1979	1975	1955
HDWD	1919	1929	1925	1913	1917	1911	1933
SGHD	1953	1950	1959	1947	1956	1949	1955
TUPE	1979	1965	1957	1979	1955	1947	1940
SYCA	1994	1990	1991	1974	1971	1977	1958
CCUT	1870	1886	1839	1855	1880	1885	1654
NVEG	1931	1885	1871	1924	1904	1903	1941
WATR	1995	1997	1996	1997	1994	1999	1998

A = 3,4,5

B = 3,4,5

C = 3,5,6

D = 2,4,5

E = 2,4,6

F = 2,5,6

G = 1,3,4

Table C-11. Averaged Transformed Divergence Values for Each of the Best Seven 4-Channel Combinations by Cover Class.

Channels

	A	B	C	D	E	F	G
SOIL	1991	1990	1992	[illegible]	1991	1992	1992
PAST	1955	1984	1976	[illegible]	1964	1980	1976
CROP	1991	1985	1983	1988	1986	1979	1981
PINE	1951	1960	1949	1939	1940	1950	1941
PIHD	1991	1997	1989	1991	1986	1989	1991
HDWD	1948	1947	1951	1941	1941	1952	1949
SGHD	1972	1968	1972	1970	1965	1972	1971
TUPE	1991	1986	1984	1990	1992	1959	1975
SYCA	1993	1996	1999	1997	1994	1993	1999
CCUT	1943	1947	1941	1945	1938	1933	1938
NVEG	1990	1975	1989	1973	[illegible]	1972	1984
WATR	2000	[illegible]	2000	[illegible]	[illegible]	1999	2000

A = 1,3,4,5

B = 3,4,5,6

C = 1,3,4,6

D = 3,4,5,7

E = 2,4,5,7

F = 2,3,4,6

G = 1,3,5,6

Table C-12. Averaged Transformed Divergence Values for Each of the Best Seven 5-Channel Combinations by cover Class.

Channels

	A	B	C	D	E	F	G
SOIL	1995	1995	[illegible]	1997	1995	[illegible]	[illegible]
PAST	1992	1991	1991	1993	1993	1990	1994
CROP	1995	1993	1993	1996	1995	1993	1998
PINE	1975	1975	1965	1962	1963	1969	1965
PIHD	1999	1999	1993	1994	1996	1999	1995
HDWD	1961	1960	1963	1957	1955	1954	1954
SGHD	1977	1976	1960	1977	1975	1972	1980
TUPE	1995	1995	1999	1995	1992	1994	1998
SYCA	1999	1998	2000	1999	[illegible]	1995	1999
CCUT	1969	1970	1962	1958	1972	1971	1962
MVEG	1997	1994	1997	1995	1987	1991	1995
WATR	2000	2000	2000	2000	1999	2000	2000

A = 1,3,4,5,6

B = 2,3,4,5,6

C = 1,2,3,4,5

D = 1,3,4,5,7

E = 3,4,5,6,7

F = 2,4,5,6,7

G = 1,2,3,5,6

Table C-13. Averaged Transformed Divergence Values for Each of the Best Seven 6-Channel Combinations by Cover Class.

Channels

	A	B	C	D	E	F	G
SOIL	1996	1998	1996	1998	1995	1995	1998
PAST	1995	1995	1996	1995	1994	1995	1994
CROP	1995	1998	1998	1996	1997	1996	1996
PINE	1983	1980	1979	1975	1979	1974	1975
PIHD	1999	1999	1999	1997	2000	1996	1994
HDWD	1970	1967	1965	1970	1966	1968	1970
SGHD	1982	1980	1980	1982	1980	1982	1963
TUPE	1999	1997	1997	1999	1999	1999	1999
SYCA	2000	1999	2000	2000	2000	2000	2000
CCUT	1980	1985	1963	1983	1982	1960	1961
MVEG	1999	1996	1996	1997	1997	1998	1998
WATR	2000	2000	2000	2000	2000	2000	2000

A = 1,2,3,4,5,6

B = 2,3,4,5,6,7

C = 1,3,4,5,6,7

D = 1,2,3,5,6,7

E = 1,2,4,5,6,7

F = 1,2,3,4,5,7

G = 1,2,3,4,6,7